Enhancing the Quality of U.S. Grain for International Trade

Volume II -- Background Papers

Part A: The Genetics of Grain Quality

1. Wheat Breeding Issues Related to Grain Quality
2. Soybean Breeding and Seed Quality
3. Grain Quality and Corn Breeding

August 1989

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Volume II --Background Papers

Part A: The Genetics of Grain Quality

Paper No.

1. Wheat Breeding Issues Related to Grain Quality by Jack F. Carter, et al.
2. Soybean Breeding and Feed Quality by Joe W. Burton
3. Grain Quality and Corn Breeding by A. Forrest Troyer

Background Paper No. 1

Wheat Breeding Issues Related to Grain Quality

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INTRODUCTION

The wheat plant and the grain borne on the plant has evolved over thousands or millions of years into the plants grown today. When early man became a seed gatherer and crude food crop culturalist in addition to a hunter, many different types of Triticum or wheat species were growing naturally for man to use as food. Early man selected types of wheat with the largest seeds over hundreds or thousands of years leading to the wheat grown in the crop agriculture present in Europe and Asia prior to migration of people to the eastern United States beginning in the 17th century. The early immigrants to the United States coming from various parts of Europe and Asia brought wheat seed with them. These wheats had been selected roughly and developed in various environments from variable native kinds or species. These variable kinds of wheat had different characteristics and were used to make different foods, leading to the different Classes having different end uses now grown in the United States.

The specific wheat Classes first were defined for classification purposes in 1916 by the United States Grain Standards Act, revised (Miller, 1987). The information used to determine numerical grade of all classes is shown in Table Intro.-1. However, these classes then and now classify botanically into at least three species having commercial significance, *Triticum aestivum* L. (hard red winter, soft red winter, hard red spring and white wheats except white club), *Triticum turgidum* L. var. *durum* (durum wheat) and *Triticum compactum* L. (club wheat including white club). Many other Triticum species (sometimes called wild types) and other close relatives of wheat are present in or near the "centers of origin" of Triticum in eastern

Table Intro.-1. Official United Standards for Wheat Used for Numerical Grade Determination, 1987, Revised.

Grade	Minimum limits of - Test weight per bushel		Maximum limits of -						
			Damaged kernels					Wheat of other classes[4]	
	Hard Red Spring Wheat or White Club wheat[1] (pounds)	All other classes and subclasses (pounds)	Heat damaged kernels (percent)	Total[2] (percent)	Foreign material (percent)	Shrunken and broken kernels (percent)	Defects[3] (percent)	Contrasting classes (percent)	Total[5] (percent)
U.S. No. 1	58.0	60.0	0.2	2.0	0.5	3.0	3.0	1.0	3.0
U.S. No. 2	57.0	58.0	0.2	4.0	1.0	5.0	5.0	2.0	5.0
U.S. No. 3	55.0	56.0	0.5	7.0	2.0	8.0	8.0	3.0	10.0
U.S. No. 4	53.0	54.0	1.0	10.0	3.0	12.0	12.0	10.0	10.0
U.S. No. 5	50.0	51.0	3.0	15.0	5.0	20.0	20.0	10.0	10.0
U.S. Sample Grade -									

U.S. Sample grade is wheat that:

(a) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

(b) Contains 8 or more stones or any number of stones which have an aggregate weight in excess of 0.2 percent of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 2 or more castor beans (*Ricinus communis* L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 2 or more rodent pellets, bird droppings, or equivalent quantity of other animal filth per 1,000 grams of wheat; or

(c) Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor); or

(d) Is heating or otherwise of distinctly low quality.

---

[1] These requirements also apply when Hard Red Spring wheat or White Club wheat predominate in a sample of Mixed wheat.

[2] Includes heat-damaged kernels.

[3] Defects include damaged kernels (total), foreign material, and shrunken and broken kernels. The sum of these three factors may not exceed the limit for defects for each numerical grade.

[4] Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.

[5] Includes contrasting classes.

Source: Miller, W. Kirk, "Grain Standards; Official U.S. Standards, Handling Practices and Insect Infestation; Final Rules," *Federal Register* 52(125):24414-24442, June 30, 1987.

Europe and Asia which can be used as parents to improve commercial wheat mentioned above and will be discussed by the wheat breeders in genetic improvement of wheat.

The term "grain quality" in the title of this paper refers to the characteristics of the wheat grain or kernel, primarily the endosperm, as it is processed (milled to flour, converted to dough, etc.) to some "end use" such as bread, pasta, cake, cookies, crackers, pizza crust, noodles, couscous, chapatties, etc. Grain quality refers entirely to the end use potential of sound kernels of the principal Class of wheat in a lot or parcel for commercial use, and in no way to the nonwheat contaminants, to FGIS grading factors for wheat directly or indirectly, or components of the wheat lot or parcel resulting from field production practices, harvest techniques or conditions, or storage or transportation conditions during marketing of the wheat from the farm to the eventual processor/manufacturer.

Wheat breeders and cereal chemists of federal and state institutions, and 18 quality laboratories of major milling companies (Crop Quality Council in 1960, Spring Wheat Quality Advisory Council since 1983), 41 commercial labs for the Hard Wheat Council, and breeders and cereal chemists of the Soft Wheat Council (the latter without a centralized system of commercial baking labs),
have cooperated closely as a "wheat improvement team," also including plant pathologists, entomologists, etc., depending upon major agronomic and grain quality objectives of the Class and region. These scientists of the wheat breeding team have at the same time been well aware that "quality," or the lack of quality, of wheat in the market place, either domestic or international, often may be interpreted by the buyers as

such physical characteristics (none of which are controlled genetically or are influenced by the breeder) as "cleanliness" meaning relative content of dockage, foreign material, dust, broken kernels, etc., relative moisture content related to condition, apparent condition related to molds, fungal infection, and blackpoint (except as resulting in bran particles in the flour or semolina), and the relative percentage of what may be classified as "nonmillable" materials. The latter percentage depends upon screen size and other cleaning components used to make the evaluation but often will include small and broken wheat kernels (the latter having possible genetic influence for kernel size or potential for kernel breakage). Sprout damage of the wheat kernel primarily is a result of wet conditions at harvest but wheats having red bran or pericarp are more resistant than white wheats to pre-harvest sprouting and breeders are attempting to breed more sprout resistant wheats, especially HRS, Durum and White Wheat (Soper, 1987).

The wheat breeding teams have attempted, quite successfully, to produce wheat varieties within the 5 Classes that meet the functional end use within the restrictions of plant heredity and selection procedures which limit the successful combination of dozens or hundreds of agronomic and end use characters into one wheat plant that is increased to become the seed for a new variety.

The reader is directed to the discussion of the authors of Chapters 1 through 4 regarding the many agronomic and end use characters desired by the wheat producer and the wheat processor, resp., and the tables in each chapter showing the relative ratings of experimentals and check varieties for each of these characters. Figure 2-1, for example in Chapter 2 on Hard Red Spring Wheat came from such reports as the Wheat Quality Program Report, 1987, (Green, 1987), in which comparative data on 9 experimental HRSW lines are compared to the check variety 'Len' based on wheat milled to flour and evaluated by 18 cooperating baking laboratories. Further, the great degree to which wheat breeders and the wheat processing industry communicate "to send signals" on needed end use quality is documented from many sources in the "1986 International U.S. Wheat End Use Quality Conference, June 9-10, 1986, Fargo, N.D. (Watson, 1986). Dr. Richard Frohberg, hard red spring wheat breeder at North Dakota State University, speaking at this conference, showed and discussed data (see Table Intro.-2) demonstrating how grain yield of such varieties as Len, Stoa and Butte had been increased by breeding while maintaining the high level of end use qualities of Waldron, a long time check variety considered very satisfactory by the processing industry (Shelton, 1986). Frohberg (Watson, 1986) compared the former check variety Waldron to 3 other HRSW varieties developed by North Dakota State University for various end use quality characters and grain yield, 1981-85, showing that end use quality had been maintained while grain yield was increased (see Table Intro.-2). (Further, Dr. Frohberg continuing 4 decades of cooperation with cereal chemists uses data in decision making to select better HRSW varieties as shown in Table Intro.-3.) Examples of other paper titles in this end use conference are (1) "Milling and Baking Performance of U.S. Hard Red Spring and Hard Red Winter Wheats from an Overseas Viewpoint" by Seiichi Nagao, Nisshin Flour Milling Co., Ltd., Japan; (2) "Wheat End Use Quality from the point of an Importer", by Kgor Sirko, International Multifoods, Minneapolis, MN; (3) "Common Interests and Concerns of U.S. Wheat Breeders, Growers and Food

Table Intro.-2. Comparison of Grain Yield and End Use Quality Characteristics of 4 HRSW Varieties at Various Locations in North Dakota, 1981-85.

Wheat Protein Content - 1981-85 Average

	Locations						
Cultivar	Dickinson	Williston	Minot	Carrington	Langdon	Fargo	Mean
	-------------------% (14.0% M.B.)--------------------						
Waldron	15.9	17.7	14.8	16.6	14.8	15.3	15.9
Len	15.3	17.2	15.0	16.6	14.6	14.8	15.6
Alex	14.6	17.7	15.2	16.5	14.6	14.8	15.6
Stoa	14.4	17.4	14.8	16.6	14.6	14.6	15.4

Quality Comparisons - 1981-85 Average

Cultivar	Test weight lb/bu	Vitreous kernels %	Flour extraction %	Wet gluten %	Flour ash %
Waldron	58.0	83	67.6	40.2	0.47
Len	59.1	85	68.5	38.1	0.47
Alex	60.3	86	66.8	39.9	0.45
Stoa	59.2	84	68.0	39.2	0.42

Quality Comparisons - 1981-85 Average

	Farinogram		
Cultivar	Peak time min.	Mixing tolerance min.	Class 1-8
Waldron	10.3	13.1	5.9
Len	12.4	15.1	7.0
Alex	11.3	15.0	6.3
Stoa	13.1	15.0	7.1

Quality Comparisons - 1981-85 Average

Cultivar	Baking absorption %	Mixing time min.	Loaf volume cc	Grain texture 1-10	Crumb color 1-10
Waldron	64.2	2.33	914	8.2	8.2
Len	65.9	3.13	937	8.3	7.6
Alex	65.1	2.53	912	8.2	8.5
Stoa	65.7	2.71	921	8.2	8.3

Table Intro.-2 (Cont.)

Grain Yield - 1981-85 Average

Cultivar	Locations						
	Dickinson	Williston	Minot	Carrington	Langdon	Fargo	Mean
	% of Waldron						
Len	109	101	104	96	117	108	106
Alex	109	105	106	105	113	110	108
Stoa	124	107	108	107	120	120	115

Table Intro.-3. Comparisons of Grain Yield and Numerous End Use Quality Characteristics of ND597 Experimental Line and 11 Named Varieties of HRSW at 23 Locations, 1983-85 Average.

					Protein 14% MB					Farinogram				3 Hour Fermentation							
Variety or number	Yld	Test wt	Vit ker	Wht* fal no	Wht	Flr	Flr ext	Wet glu	Flr ash	Peak time	Mix Tol	Mti	Class	Abs	Mix time	Do	Loaf vol	G-T	CB CL	CT CL	Sym
	Bpa	lb/bu	%	Sec	%	%	%	%	%	min	min	bu		%	min		cc				
Alex	48.4	60.0	83	461	15.8	15.1	66.7	41.0	0.47	13.0	16.2	20	6.4	66.4	2.55	10.0	945	8.2	8.4	10.0	9.9
Butte	48.2	59.7	77	454	15.3	14.3	68.2	39.6	0.42	10.8	13.7	23	5.9	67.4	2.30	10.0	899	8.1	8.0	9.9	9.4
Challenger	47.9	59.2	61	437	14.7	14.0	70.9	34.2	0.45	16.6	17.2	16	7.1ab	61.3	3.75	9.9	855	7.9	8.7	10.0	8.7
Columbus	43.8	58.9	82	523	16.6	15.7	67.5	45.3	0.48	8.6	10.9	26	5.3	68.0	2.05	10.0	927	8.1	8.0	10.0	9.7
Erik	47.8	57.5	76	489	15.4	14.5	68.0	37.8	0.48	12.4	15.5	20	6.4	64.9	2.50	10.0	888	7.9	7.6	10.0	9.4
Guard	49.3	59.1	70	472	14.9	14.1	67.0	35.5	0.46	13.0	17.0	18	6.2	65.3	3.60	10.0	893	7.9	8.3	10.0	9.5
Len	47.8	58.6	83	446	15.7	14.9	68.1	38.5	0.48	13.6	16.1	18	7.1	67.2	3.20	10.0	951	8.3	7.6	10.0	10.0
Marshall	49.5	58.5	78	475	14.9	14.1	69.9	38.6	0.44	9.1	13.1	23	5.6	62.6	2.05	10.0	871	7.8	8.1	10.0	9.3
ND 597	48.1	59.3	78	497	15.6	14.6	66.1	40.6	0.45	11.8	13.4	25	5.9	69.0	2.20	10.0	881	8.2	8.5	10.0	9.5
Stoa	51.7	58.6	82	467	15.7	15.0	67.6	39.9	0.44	14.4	16.9	16	7.2	66.9	2.80	10.0	954	8.3	8.4	10.0	10.0
Waldron	45.1	57.4	79	448	16.0	15.2	67.5	41.0	0.49	11.8	13.9	22	6.0	65.4	2.40	10.0	944	8.3	8.2	10.0	10.0
Wheaton	52.8	57.4	74	465	14.7	13.7	69.1	35.0	0.46	14.5	14.8	20	6.6	64.6	2.95	10.0	900	8.0	8.4	10.0	9.6

* The values given are for the years 1983 and 1985.

Source: 1986 Annual Report, R.C. Frohberg, NDSU.

Processors", by Robert Morris, Continental Baking Company, St. Louis, MO; (4) "Viewpoints on Wheat Quality", by Max Jones, Campbell Taggart, Dallas, Texas; (5) "Wheat Breeding at North Dakota State University" (HRSW), by Richard Frohberg, NDSU, Fargo, ND; (6) "Milling and Baking Performance of U.S. Wheat from a Plant Breeder's Viewpoint" (HRWW), by Rollie G. Sears, Kansas State University, Manhattan, KS; and many others including a "question and answer period" to communicate. In addition to the repetition of the numerous end use characters by the millers/processors at the end use conference two processors emphasized two very important characteristics (1) uniformity of the wheat raw material in the marketplace available for milling, and (2) resistance of the composite flours and ingredients to environmental changes in a bakery, or among bakeries of the same company at different locations, especially in the high speed baking processes of modern bakeries.

The reader should understand and be alert to the discussions in Chapters 1 through 4 that only Test Weight, of the table of Official Wheat Standards determining numerical grade of wheat, as it influences flour yield and potential starch damage as kernel density varies, influences the end use quality of sound (not damaged by external forces) wheat kernels of the principal class in the lot or parcel of wheat.

The major objective of this paper is to establish that for about 75 years, variably among Classes, wheat breeding teams have evaluated prospective wheat varieties for desirable end use characteristics as perceived to be required by the wheat processing industry. The needs of the wheat processing industry have been communicated to the wheat breeder by the consumer, miller and baker, by such trade organizations as the Crop Quality Council (now the Spring Wheat Quality Advisory Council), the Hard Wheat Council, State Wheat Commissions or Councils, U.S. Wheat Associates, and other so-called "institutional influences."

A very high percentage of all wheat varieties released have been evaluated and perceived to reasonably meet the end use quality characteristics of the processor. The grain quality of a commercial wheat variety then is designed to meet the needs of the processor. Therefore, nonwheat components of any lot or parcel of wheat fitting the wheat Class requirements of a single Class of wheat should not imply that the parcel has poor quality. The nonwheat components, sometimes called "nonmillable components" such as foreign material, dockage, and perhaps broken wheat kernels in some lots, should not reflect negatively on the sound grain quality of the principal Class of the wheat parcel, either domestic or for export.

In fact, nothing except minimum Test Weight, in Table Intro.-1 of the Wheat Standards in the Official United States Standards for Grain (Miller, 1987) revised, used to determine numerical grades of pure, sound (not damaged) wheat, is a character or property listed as important for end use by cereal chemists or millers (Green, 1987). Test weight or thousand kernel weight are considered to be positively correlated to flour yield of milled wheat especially within a variety or closely related genotypes (see Figure Intro.-1, Figure 10-1 of Heyne, 1987), but less well positively associated in mixtures of many genotypes or varieties as often occurs in the commercial wheat trade. Actually flour yield is more an economic factor than end use factor if ash percentage and starch damage are within acceptable ranges. The association of test weight, flour yield and flour ash percentage is

Figure Intro.-1. The Relationship of Flour Yield and Flour Ash to Test Weight in Two Hard Red Winter Wheat Varieties.

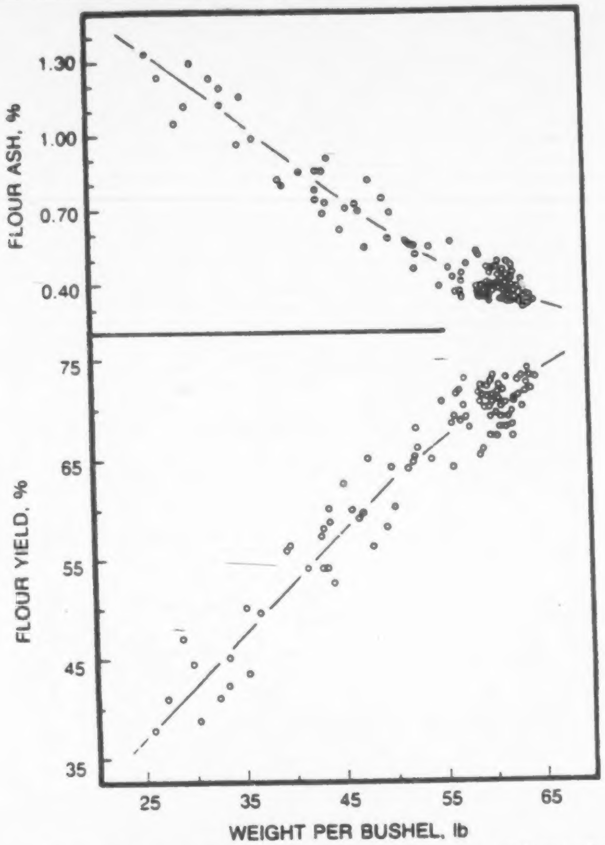

Fig. 10-1. Weight per bu vs. flour yield and flour ash for 'Pawnee' and 'Kaw' wheat harvested at varying stages of maturity at Manhattan, KS, in 1948, 1949, 1950, 1951, 1961, and 1962.

Source: Wheat and Wheat Improvement, Agronomy Monograph No. 13 Revised, 1987. (Use of copyrighted material approved).

shown in Figure Intro.-1 for 'Pawnee' and 'Kaw' HRWW as reproduced from Finney et al. (Heyne, 1987). Finney et al. state that as test weight decreases, especially from kernel shriveling, an increase in ratio of bran to endosperm occurs, and a concomitant flour yield loss. "Milling studies conducted on Pacific Northwest soft wheat have shown a decrease in yield of about 1% as well as an increase in flour ash content of about 0.025% for each 1-lb decrease in test weight within a test weight range from 64 to about 30 lb./bu for the grains tested (Heyne, 1987)." The authors of Chapters 1 through 4 of this paper state that test weight is positively correlated to flour yield, most highly within a variety or closely related germplasm, less close association in more diverse materials, e.g., commercial grain composed of many varieties grown under variable conditions, where discounts to growers may be applied at country elevators to wheat having test weight below 60 lbs./bu.

Three scientists in Canada (Dexter, Matsuo and Martin, 1987) recently reported on the relationship of durum wheat test weight to milling performance and spaghetti quality of durum wheat from crop years 1984 and 1985. They found highly significant positive relationships between test weight, milling performance and spaghetti quality. A 1-kg decrease in TW was associated with a linear 0.7% decrease in semolina yield with a negative association (increase) in semolina ash with decreased TW. Kernel weight and kernel size distribution were strongly related to TW and equal as predictors of semolina yield potential. Semolina became duller as TW declined and ash increased. The only beneficial effect of lower TW was increased protein percentage of wheat and semolina and improved cooked spaghetti firmness.

Other factors in Table Intro.-1, again not listed as specific end use characters by cereal chemists or millers but having indirect relation to end use quality only if some of the wheat kernels are not sound, (not applicable to sound kernels), are as follows, the factor and indirect influence: (Maximum limits of following factors):

Heat damaged kernels: Atypical milling performance and increase of dark speck counts in the flour or semolina, probably atypical tempering also; wheat kernel damage of any kind may influence the milling and baking properties of all wheat Classes.

Total damaged kernels, which includes sprout, insect, frost, sick wheat, blackpoint, scab or other mold damage: Sprout damage increases amylase content of kernels and lowers falling numbers tests, both undesirable, if excessive, for many end use products; "sick" wheat would cause responses similar to heat damage; insect damage leads to insect fragments in flour, atypical tempering due to broken pericarp and reduced yield of both flour and by-products; frost damage damages or breaks the pericarp or bran and leads to atypical tempering and milling, possibly excessive breakup of the bran in milling to increase speck count in flour or semolina; blackpoint, scab or other mold injury to the pericarp or bran results in atypical milling performance, increased black specks in the flour or semolina (Finney et al, 1987), etc. Wheat breeders have created and are further improving resistance of the wheat plant to the molds (diseases) such as blackpoint, and the plant resistance is imparted to the bran of the kernel so breeding for plant resistance implies resistance of the whole plant including the wheat kernel. Wheat kernel damage of any kind may influence the milling and baking properties of all wheat Classes.

Foreign material: Foreign material is a dilutant although some types, if not removed in cleaning before milling, could result in atypical milling, specks in flour, etc.

Contrasting classes and total wheat of other classes: Contrasting refers to wheats other than the principal class having a different end use. Minor or small percentages of other classes in the principal class may have a variable, even favorable, influence on the end use, e.g., a small amount of HRSW in HRWW, and research data would indicate that small admixtures of classes have limited influence on end use unless the class admixture results in the Mixed Wheat classification.

Shrunken and broken kernels alone and as a component of total defects: This factor is determined by sieving and contains both small and broken wheat kernels and foreign material such as small weed seeds that will pass through a 0.064 and 3/8 inch slotted sieve after dockage is removed. The proportion of kernel sizes sometimes is used as a factor determining relative value for end use. Some users of U.S. wheat in foreign countries apparently use sieves with larger holes thus increasing percentage of "nonmillable" materials. The percentage of "shrunken and broken" will decrease net flour yield from the beginning lot and small or broken kernels remaining in the cleaned wheat for milling can influence usual tempering and milling procedures.

However, it should be repeated that none of the factors in the table determining numerical grade of wheat, except test weight, is in the usual list of "end use quality factors" used by cereal chemists who cooperate with wheat breeders or those in the milling trade, and none of them except Test Weight should influence the end use quality of sound grain of the principal class of a lot or parcel. The reader should refer to the appropriate tables on end use quality evaluation of experimentals to control or check varieties in Chapters 1 through 4.

Class or subclass are not in evaluation tables for end use quality characters. However, percentage dark, hard and vitreous or hard and vitreous kernels may be one factor listed by cereal chemists supplemented with protein percentage. Mixtures of either hard or soft kernels in the principal class may indirectly influence flour yield and/or starch damage as milled and processed, thus influencing the intended end use for a specific lot or parcel of wheat.

Protein percentage almost always is supplied on the grade certificate identifying the "kind and amount" of a wheat parcel but protein percentage is not a determinant of numerical grade, Class or Subclass of wheat. Class and subclass determinations are made on the basis of kernel morphology and, again, are related only indirectly to grain quality for end use based on common usage in the wheat industry. Flour, dough, bread, pasta, or cake or cookie characteristics do not occur in the official wheat standards. The relative hardness or vitreous nature of the wheat kernels may relate to protein percentage, starch damage and semolina yields, flour yield and other milling properties but are not interpreted easily by visual inspection and are inherited complexly.

This report will provide information on the five principal Wheat Classes to educate the reader and provide justification for the above statements.

Wheat breeders have been breeding for improved "end use performance" in wheat for decades, although the beginning dates may vary by Classes. The "AC Mill" (AC for Agricultural College) was placed in use as a pilot mill to help evaluate hard red spring and durum wheat in 1909 at the North Dakota Agricultural Experiment Station, Fargo, ND, (Moran, 1985). Milling and baking performance and protein percentage, the latter via the Kjeldahl method, were determined on commercial grain produced (a quality survey) and very soon end use quality analyses were performed on wheat breeding progenies versus a standard check variety for hard red spring wheat breeding programs at the Dickinson Experiment Station, ND, and from the wheat breeders of the Plant Industry Division, USDA, located at the Northern Great Plains Field Station, Mandan, ND. Also, at least two courses in cereal chemistry related to end use were taught at the North Dakota Agricultural College about 1908-09. The Cereal Technology Department, NDAES, began quality analyses on durum wheat re pasta end use in 1938 (Moran, 1985). The Soft Red Winter Wheat Quality Lab was started at Wooster, Ohio, in 1937, and the Hard Red Winter Wheat Quality Lab at Manhattan, Kansas, in 1938. The Hard Red Spring and Durum Wheat Quality Lab of the ARS, USDA, was moved to the North Dakota Agricultural Experiment Station in 1962, after transfer from Beltsville, MD, where it was started in 1915 (Fifield and Clark, 1929), and associated with Cereal Technology and Chemistry as a regional facility to perform end use quality analyses for wheat breeders in other states*.

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*See excerpt from Fifield and Clark the following 2 pages describing first hard red spring wheat quality analyses in 1915 by AMS, USDA, Beltsville, MD.

UNITED STATES DEPARTMENT OF AGRICULTURE
Bureau of Plant Industry

MILLING AND BAKING EXPERIMENTS WITH HARD RED SPRING WHEATS

by

C. C. Fifield, associate baking technologist, and J. Allen Clark[1], senior agronomist, Wheat Investigations, Division of Cereal Crops and Diseases.

The purpose of this report is to summarize the results obtained from varieties of hard red spring wheat grown in plots at agricultural experiment stations in the spring wheat region of the United States since 1929. In that year, a Cooperative Regional Improvement Program was organized by Federal and State institutions and workers in Minnesota, North Dakota, South Dakota, Montana, and other neighboring States. This regional program has been in progress for seven years and the varietal experiments have been conducted in plots during one or more years at 27 stations.

The milling and baking experiments were conducted for two purposes: (1) To determine the relative technical value of the uniform and other commercial varieties grown at the stations; and (2) to aid in the breeding of new varieties for improving the quality of wheat. The uniform varieties are the leading commercial varieties grown in the region and the most promising new varieties developed at the experiment stations. The wheat breeders in the U.S. Department of Agriculture cooperate with those in the State Agricultural experiment stations in the breeding of high yielding wheats, resistant to diseases and drought, and which are also of good quality.

Before a new variety is distributed for commercial growing, different agencies test its milling and baking qualities to determine if it will meet the demands of the market. The Division of Cereal Crops and Diseases conducts its experiments in the Milling, Baking, and Chemical Laboratory of the Bureau of Agricultural Economics. The results of these cooperative experiments aid in the promulgation and enforcement of the Federal grain standards for wheat. Other agencies conducting similar experiments with new varieties of spring wheat are the State milling and baking laboratories of the Minnesota, North Dakota, and Montana agricultural experiment stations and several leading milling companies through the Northwest Crop Improvement Association.

The results obtained by the different agencies furnish a basis for recommending the production of new varieties of satisfactory quality and the reduction in acreage of varieties of poorer quality.

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[1] The writers wish to acknowledge the work of J. F. Hayes, Ray Weaver, S. R. Snider, C. E. Bodo, D. Martin, P. Talbot, and Alfred Christie, in conducting the milling and baking experiments and to express appreciation to C. C. Colcord and A. J. Novotny for their assistance in calculating and tabulating the data.

The Regional agronomic and pathological results have been summarized annually and one previous milling and baking summary has been presented. Further results, obtained by the United State Department of Agriculture, are summarized briefly in this report. The data for each station have been supplied annually to the local workers.

Milling and baking experiments with varieties from experiment stations were begun by this Department in 1915 with a uniform set of spring wheat varieties from eight stations in the Great Plains area. The results of 1,310 samples of hard red spring wheat, milled during the 7-year period, 1915-21, together with those of other wheat classes, were published in U.S. Dept. Bull. 1183, Milling and Baking Experiments with American Wheat Varieties. Similar experiments continued for the 7-year period, 1922-28, were summarized and are on file in the Division of Cereal Crops and Diseases.

THE BAKING TEST

Starting with the Cooperative Regional Improvement Program and the samples of the 1929 crop, the methods and equipment were changed to the basic method recommended by the American Association of Cereal Chemists.

The change reduced the amount of flour used from 340 g to 100 g, made the water absorption constant, and eliminated the shortening.

Basic Method

The new method (generally termed the pup loaf) was thought to be better for determining differences between varieties and classes and was as follows:

Ingredients	
Flour	100 g (15 percent moisture basis)
Sugar	2.5 percent
Salt	1.5 percent
Yeast	3.0 percent
Water	58.0 percent

Fermentation time	
First punch after	105 minutes
Second punch after an additional	50 minutes
Mold after an additional	25 minutes
Total	180 minutes
Proofing time	55 minutes
Baking time	25 minutes, at 230°C.

This method, first used on the varietal samples of the 1929 crop, proved unsatisfactory and slight changes were made in the method in succeeding years. A shorter fermentation period (160 minutes) and increased water (60 percent) or variable absorption (sufficient water to yield a dough of standard consistency) were used in baking during the next three years.

The Wheat Quality Lab at Washington State University, Pullman, Washington, was started in 1946 to interpret end use characters for wheat breeders of the Pacific Northwest. More recently, private laboratories have been established to provide end use quality evaluations for both commercial wheat samples and those submitted by primarily wheat breeders for private seed companies. Also, some of the larger private seed companies have established their own laboratories to evaluate end use quality of wheat progenies produced by their wheat breeders.

The wheat quality laboratories of the USDA and departments of Cereal Science, Grain Science or equivalents at Agricultural Experiment Stations and organizations such as the former Crop Quality Council (now Spring Wheat Quality Advisory Council) have evaluated wheat experimentals versus standard check varieties for end use qualities via annual reports for several decades (CQC began in 1960). The end use characters of HRSW in 1987 are almost identical to those evaluated in 1960 except for the coding of the data. Only 5 checks or control varieties of HRSW have been used in 27 years, Thatcher, Selkirk and Conley, Chris, Waldron and Len, the latter in 1985-87. (Kharkov and Scout have been long time quality checks in the HRSW nurseries along with local varieties because of the wide geographic distribution; Trumbull, Knox 66 and Caldwell have been long time checks for end use quality in SRWW again along with local checks in the Eastern and Southern nurseries.) A comparison in Table Intro.-4 of the end use quality characteristics for hard red spring wheat in 1960 as indicated by the Crop Quality Council, which were the same or similar to those of the earlier Northwest Crop Improvement Association, to those in the

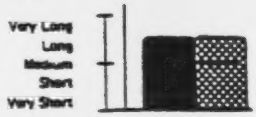
Table Intro.-4. The Composited Tables from the 1960 Report of the Crop Quality Council and the 1987 Report of the Spring Wheat Quality Advisory Council Show the Very Close Similarity of End Use Quality Characters Apparently Desired by the Wheat to Flour Processing Industry, Including the Bakers.

1960 Harvest				
Station				
Experiment No.		1	2	3
Variety		Selkirk	Conley	ND137
Test Weight		61.0	63.0	61.5
Wheat Prot. (14.0% M.B.) (Pills.)		10.7	11.7	11.9
Flour Prot. (14.0% M.B.) (Pills.)		9.7	10.7	10.8
Flour Ash (14.0% M.B.) (Pills.)		.394	.405	
Farinograph:	Absorption	62.3	64.3	66.2
	Arrival Time	1.3	1.5	1.5
	Peak	2.3	2.5	2.3
	Stability	3.0	3.5	3.5
	M.T.I.	85	60	60
Flour Color:				
Before Bleaching (VG,G,F,P)*		VG92	G 89	G 86
If F or P, Why?	Yellow			1
	Dull			1
	Yellow & Dull		1	
After Bleaching (VG,G,F,P)*		VG97	VG96	VG93
If F or P, Why?	Yellow			
	Dull			
	Yellow & Dull			
Flour Absorption:	Strong Type Flour	60.1	62.1	63.7
	Bakers' Pan Bread Flour	61.6	63.3	64.2
Loaf Volume: (Index)	Strong Type Flour	100	101	101
	Bakers' Pan Bread Flour	100	102	102
External Appearance: (VG,G,F,P)*	Strong Type Flour	F 75	F 78	F 77
	Bakers' Pan Bread Flour	F 79	G 82	G 82
Internal Characteristics:				
Crumb Color: (VG,G,F,P)*	Strong Type Flour	F 78	G 82	G 81
	Bakers' Pan Bread Flour	G 83	G 88	G 86
Crumb Grain: (VG,G,F,P)*	Strong Type Flour	F 76	F 78	F 76
	Bakers' Pan Bread Flour	G 84	G 87	G 84
Dough Characteristics: (VG,G,F,P)*				
As a Strong Type Flour		F 71	F 72	F 71
If F or P, why?	Bucky			
	Short			1
	Sticky	2	1	1
	Weak	6	6	6
As a Bakers' Pan Bread Flour		F 76	F 79	F 78
If F or P, why?	Bucky			
	Short	1	2	2
	Sticky	2		1
	Weak	8	6	5
CONCLUSIONS:				
Mixing Time Required:	Long	3	3	3
	Medium	1	4	4
	Short	10	7	7
Mixing Tolerance		F 71	F 73	F 73
Fermentation Time Req:	Long			
	Medium	6	7	6
	Short	4	3	4
Fermentation Tolerance		F 77	G 83	G 81
Response to Oxidizing Agents		G 82	G 84	G 83
General Rating:				
Strong Type Flour		P 68	F 70	F 70
Bakers' Pan Bread Flour		F 76	F 79	F 78
Numerical Ranking in Each Station Group:				
Strong Type Flour	Rank	4	2	1
	Ave.	2.8	2.1	2.0
Bakers' Pan Bread Flour	Rank	3	2	1
	Ave.	2.7	2.2	1.8

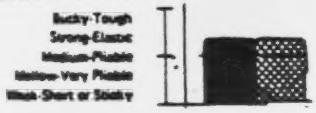
VG	90 to 99
G	80 to 89
F	70 to 79
P	60 to 69

1987 Harvest				
Location				
Variety			Len	s - 2
1	Wheat Protein %		16.3	16.4
2	Flour Protein %		15.5	15.4
3	Test Weight		62.8	63.0
4	1000 Kernel Weight (Grams)		37.5	36.8
5	% Large Kernels		65	60
6	% Small Kernels		1	1
7	Wheat Ash %		1.55	1.47
8	Flour Extraction %		69.56	67.19
9	Flour Ash %		.38	.39
10	Pounds 0.46% Ash Flour per cwt. wheat		77.25	75.80
11	Farinograph:	Absorpton %	65.5	66.0
		Arrival Time	7.0	4.5
		Peak	17.5	17.0
		Stability	23.0+	25.5+
		M.T.I.	10	0
12	Bake Absorption (14% M.B.)		66.0	66.2
13	Loaf Volume (% of Check)		100	100.2

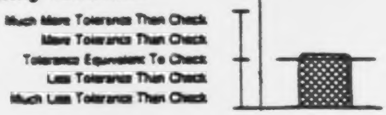
14 Mixing Requirement



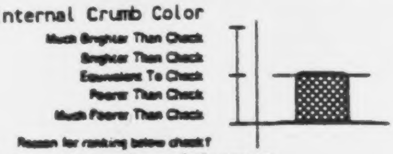
15 Dough Characteristics



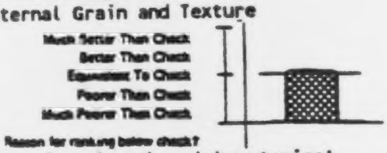
16 Mixing Tolerance



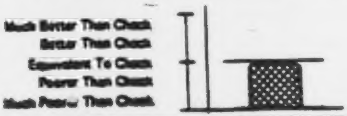
17 Internal Crumb Color



18 Internal Grain and Texture



19 Comparison based on laboratories' considerations of all categories (1-18)



· Difference is statistically significant at the 5% level.

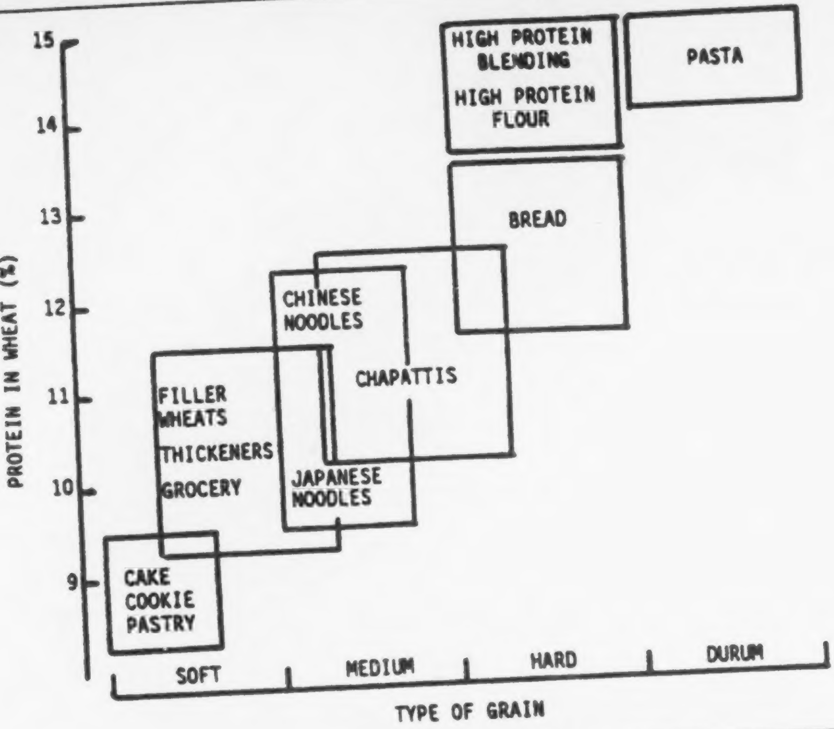
†Most frequently reported comment.

Source: 1960 Report of Crop Quality Council and 1987 Report of Spring Wheat Quality Advisory Council.

1987 report of the Spring Wheat Quality Advisory Council show them to be remarkably similar, and that the Len check for 1987 is equal or better than the Selkirk check of 1960.

Figure Intro.-2 was prepared by Paul Mattern, Cereal Chemist and one of authors of Chapter 1. Protein percentage of the wheat kernel is plotted versus relative kernel hardness as related in a general way to the end use of various wheats. Protein percentage, kernel hardness and many other characteristics of the wheat grain are discussed related to end use performance in Chapters one through four on five wheat Classes.

Figure Intro.-2. A Diagrammatic Representation of Relative Protein Percentage Plotted Versus Kernel Hardness Characteristics of Various Wheats as Determinant of End Use.



PROTEIN IN WHEAT (%)
15
14
13
12
11
10
9
HIGH PROTEIN BLENDING
HIGH PROTEIN FLOUR
PASTA
BREAD
CHINESE NOODLES
CHAPATTIS
FILLER WHEATS
THICKENERS
GROCERY
JAPANESE NOODLES
CAKE
COOKIE
PASTRY
SOFT
MEDIUM
HARD
DURUM
TYPE OF GRAIN

Protein content and hardness characteristics of wheats required for different end uses. [Adapted from Figure 2, H. J. Moss, Aust. Inst. Agric. Sci. 39:109 (1973)].

Wheat protein and hardness for various end uses follows definite requirements. Low protein soft wheats produce the smallest particle size flour with the lowest starch damage for use in cakes, cookies and pastries. "Grocery" flour refers to the "all-purpose flour" for home use. Hard wheats produce a bread flour with the required protein and starch damage percentage. Pasta is made from durum wheat which is the hardest of all commercial wheats in the United States. Durum wheat is processed into a coarse semolina product to produce lower acceptable levels of starch damage.

In addition to the protein and hardness levels shown in this figure, the wheats must have been selected for specific "protein quality" factors during their development in a plant breeding program.

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CHAPTER 1

HARD RED WINTER WHEAT (HRWW)

Definition of Wheat Quality

Physical Characteristics Influencing Grain Milling Quality

Biochemical and Functional Characteristics for Grain Quality in HRWW

Dough Mixing Properties

Protein (Gluten) Properties

Carbohydrates of HRWW

Minor Biochemical Components of HRWW Flour

Hemicelluloses and Pentosans

Lipids (Fats)

Mineral Elements in Wheat Grain or Flour

Objectives of Genetic Selection

Physical Characteristics Related to Grain Quality

Major Agronomic and End Use Characters

Biochemical Characteristics

Institutional Influences of Plant Breeders

Use of Wheat in Future Traditional Roles

Use of Wheat in Future Non-Traditional Roles

Genetic Influence on Wheat Quality

Interactions Among Grain Yield, Grain Quality and Disease Reactions

Genetic Influence on Physical Quality

Genotypic Variability of End Use Quality Traits

Genotype and Environmental Interactions Affecting Quality

Variety Release

CHAPTER 1

HARD RED WINTER WHEAT (HRWW)

The Definition of Wheat Quality

Wheat quality is determined by distinguishing characteristics which contribute to its performance as used in the wheat industry. The breeder, farmer, merchandiser, miller, baker and consumer may each have a different definition for wheat quality. Hard red winter wheat (HRWW) is the largest class of wheat in the United States in acreage and production and is grown in a greater diversity of environments than any of the other classes of wheat. HRWW is grown in virtually every major wheat producing state in the midwest and western United States. A wide range of grain quality may occur within the HRWW class depending upon where the crop was grown, i.e., South Dakota, Kansas, Montana or Texas.

HRWW is used primarily in yeast leavened dough products, principally white pan bread. Quality factors for bakery flour include protein level, quality of the protein, and possibly other factors which assures the production of a loaf of bread with consumer appeal.

Physical Characteristics Influencing Grain Milling Quality

Kernel shape and size can affect flour yield of the milled wheat kernels. HRWW because of the longer, larger kernels generally has higher flour yields than hard red spring wheat. Prior to milling, wheat is "tempered", a process in which water is added to bring the moisture content to 15% to 16% (for hard wheats) within 18 to 24 hours. Tempering toughens the outer bran layer so that it will not shatter and softens the endosperm to permit proper reduction to flour. Wheat must mill efficiently by providing easy separation of bran from the flour. Bran is sold as a feed ingredient at a lower price than flour, so any flour not recovered is a loss to the miller. The miller maintains humidity and temperature conditions to produce a flour at approximately 14% moisture. This level provides safe storage conditions and best economic return because flour is sold on a weight basis.

Wheat consisting of a mixture of small and large kernels does not come to a uniform moisture content during tempering. Non-uniformity of kernel size causes an additional problem on the "first break" rolls in the mill. If roll spacing is correct for large kernels, the small kernels will pass through untouched and if rolls are set for the small kernels, the large would be reduced too far and produce excessive bran contamination.

Wheat kernel hardness is an important quality factor because it contributes to the amount of starch damage produced during milling. Starch consists of discrete granules in endosperm cells and is modified during milling by roll pressure and heat. The major affect of starch damage is to increase water absorption during dough formation and to increase the rate of enzymatic digestion to produce sugars for yeast metabolism during dough fermentation.

Hard wheats typically produce 7% to 9% starch damage, and the soft wheats 3% to 4%. The final level of starch damage is controlled by kernel hardness and milling procedures.

Biochemical and Functional Characteristics for Grain Quality in HRWW

Bread is defined as a product made of flour, water, yeast and salt. Bake absorption is the amount of water, expressed as a percentage of the flour weight, required to produce a dough having the necessary physical handling and machining characteristics to produce a satisfactory bread product. Protein and damaged starch absorb 1.1 and 2.0 times their weight of water, respectively, and so influence final bake absorption (Greer and Stewart, 1959). Requirements for starch damage and amylase vary depending on the bread making techniques. In fast bread making processes using mechanical or chemical dough development, the need for fermentable sugars from starch damage is minimal. However, starch damage is important in long fermentation methods such as the sponge and dough process.

Dough Mixing Properties

As flour, water, yeast and salt are mixed with appropriate equipment, a dough develops. Wheat flour is unique in its ability to form an extensible dough. The dough "develops" and reaches optimum properties at the so-called Flour Mixing Time. This time, given in minutes, is the point at which the dough has good mechanical handling properties and is capable of producing the best possible loaf of bread. Mixing time is a genetically controlled factor which will be further discussed with protein (gluten) characteristics. In addition, the dough has a "mixing tolerance," or the ability to maintain useful properties with some overmixing. Overmixing can produce "sticky" doughs which cause the baker to have production problems and/or poor bread quality.

Long mixing times are associated with greater mixing tolerance. However, long mixing increases power use and costs, therefore, new wheats are developed with a reasonable range of mixing times and mixing tolerances from which the miller can select acceptable blends for bread flours.

Bakers would like identical (consistent) flour properties with each purchase but changing varieties, market blending practices, and environmental effects during wheat growth, make this impossible. Mill operators, through selection and blending, provide the baker with the most consistent flour possible. As baking processing speeds increase, flour specifications become more critical and may need to be changed. For example, a finer flour with a narrow range in particle size functions more efficiently with high speed mixers.

Protein (Gluten) Properties

Bakeries require a flour protein percentage of approximately 11.5% (on a 14% moisture basis) for white pan bread. Since 1% of protein is lost from wheat to flour in milling, the protein percentage of the mill blend should be 12.5%. Both quantity and quality of wheat protein are important in meeting flour specifications to make white pan bread. Therefore, wheat of appropriate class must be used to meet the baker's specifications.

Wheat endosperm proteins often are classified according to their solubility expressed as a percentage of the total protein as follows: water soluble albumins, 5 to 10%; salt soluble globulins, 5 to 10%; alcohol soluble gliadins, 40 to 50%; and alkali soluble glutenins, 30 to 40%. The gliadins and glutenins known as the seed "storage proteins" comprise approximately 85% of the endosperm proteins. During dough development they form the unique rubber like mass known as gluten. This water insoluble protein (gluten) holds the carbon dioxide gas produced during yeast leavened fermentation and forms the porous structure for bread. As protein percentage of a flour increases in a cultivar the gliadin fraction increases and the glutenin decreases (Ulmer, 1973).

Carbohydrates of HRWW

The carbohydrates of wheat may be classified into three groups: (a) monosaccharides or simple sugars, which consist of five-carbon compounds such as xylose and arabinose, and six-carbon compounds, such as glucose and fructose; (b) oligosaccharides, in which two or more, but fewer than ten simple sugars are combined in a linear structure; (c) polysaccharides such as cellulose, hemicellulose and lignin, which are important in plant structural materials, and starch, the nutrient polysaccharide that is important as an energy source in nutrition.

Starch, a glucose polymer, is formed in discrete small and large granules and is found enmeshed within the dried endosperm cell contents. Small granules comprise 10 to 25% of the total starch. Starch granules are spherical in shape with a mean diameter of 5 to 7 micrometers. Large granules are lenticular in shape and have a mean diameter of 23 to 35 micrometers. Two types of starch polymers are found. Amylase is essentially a linear structure and amylopectin is highly branched. Starch makes up 60 to 75% of the kernel weight and varies inversely with protein percentage.

Minor Biochemical Components of HRWW Flour

The term minor refers to the quantity of flour constituents and not necessarily to their importance in baking.

Hemicelluloses and Pentosans. The names hemicelluloses and pentosans often are used interchangeably and include the many sugar polymers but exclude starch and cellulose. Some workers use the term pentosan for the water soluble materials. The hemicelluloses in wheat flour are thought to be cell wall components. They are polymers of five and six carbon-ring sugars and also may be associated with proteins, phenolics and other compounds.

Wheat flour consists of about 2.4% water insoluble hemicelluloses and from 1.0 to 1.5% water soluble pentosans. Because of their ability to hold rather large amounts of water they undoubtedly influence dough rheology properties.

Lipids (Fats). Lipids of a whole wheat generally range from 2 to 4%. The so-called "free" lipid, which can be extracted with petroleum ether, is a smaller amount ranging from 1.4 to 2.6%. Morrison (1978) has discussed lipids in wheat and wheat fractions. Lipid material is not dispersed evenly throughout cereal kernels. The embryo (germ) of wheat contains 30% of its weight as oil. The endosperm is lowest in oil and the outer layers are intermediate between the germ and the endosperm. Wheat germ oil includes a high proportion of unsaturated fatty acids.

Davis, et al. (1980) evaluated the lipid composition of five market classes of wheat involving 124 varieties, 3 crop years, and 40 growing locations. However, samples were not selected to evaluate genotype and environment interaction. Total lipids ranged from 0.88 to 3.33% with a mean of 2.34% (dry weight basis).

Mineral Elements in Wheat Grain or Flour. Mineral element research has had recent break-throughs reminiscent of those of past vitamin research. Since 1975 an additional five minerals (arsenic, nickel, silicon, tin and vanadium) have been suggested as being essential for animal nutrition.

Flour ash (total minerals) has traditionally been used to price flour, not from the aspect of nutrition but as a measure of the extraction rate used by the miller. High ash indicates contamination with bran. The baker wants a low ash value for a white bread crumb color, and to ensure that the protein percentage of the flour reflects the better quality endosperm proteins.

Objectives of Genetic Selection

Physical Characteristics Related to Grain Quality

Major Agronomic and End Use Characters. Wheat breeders can only improve those traits controlled and inherited genetically. Genetic variation accounts for various proportions of each trait influencing wheat quality. For example, protein percentage of the wheat kernel is a heritable trait controlled by genes in the wheat plant. Plant breeders can select for high protein and identify genotypes which produce high protein in the kernel. Protein percentage also is influenced by the environment, i.e., fertilizer applied, moisture for crop growth, air temperature during grain filling, etc. Variation in protein percentage selected for under field conditions can be due to both genetic and environmental factors. Generally the larger the number of genes controlling a specific trait, the lower the heritability, and the larger the environmental influence. Traits with high heritabilities are affected little by the environment, and therefore are easier to select and stabilize in a variety. Below are important traits that are selected in HRWW breeding programs.

1. Yield, all selections must have at least equal yielding ability compared to the competitive check. Yield has a low heritability.
2. Test weight, is weight per unit volume and is considered a measure of the soundness of grain, and may be correlated with flour yield. Test weight has intermediate heritability.

3. Kernel morphology, influences the classification of wheat and has served as the official method to identify end use. A large number of genes influence kernel morphology which is considered to have low heritability (Sears, 1986). Kernel morphology does not affect end use properties in any way, except perhaps flour yield.
4. Kernel density and size distribution, selected for visually, allows for easier milling and high flour yields. Kernel size and uniformity have intermediate heritability.
5. Kernel appearance, hard vitreous kernels are selected. Grain protein percentage and vitreous kernels are not correlated highly (Pomeranz, et al., 1985). Hard vitreous kernels are necessary for functional HRWW bread baking properties. Hardness has a high heritability. Table 1-1 lists the type of variation one might expect for hardness in a genotype grown at different locations in Nebraska.
6. Disease resistance, each breeding program must consider reaction of progeny to different important diseases, depending upon location and environments. Healthy plants produce healthy grain. The majority of the genes affecting disease resistance are highly heritable.
7. Abiotic stress tolerance would include primarily heat and drought tolerance and winterhardiness. These traits are extremely important in the Great Plains where abiotic stresses occur every year. Each is controlled by several different genetic mechanisms and both have low heritabilities.
8. Agronomic appearance, plant breeders select for a specific plant type based upon experience. Wheat varieties need to have short

Table 1-1. 1986 Nebraska Intrastate Nursery Wheat Samples (Selected Varieties for Hardness Study) 4 Locations, 50 Kernels Microscopic Hardness Evaluation (1986 Samples Run in 1987).

		1	2	3	4	5	6	7	8	9	10	Mean
		-------(1 - 10 = Soft - Hard)---------										
BENNETT	Sidney				11	22	17					5.12
	Alliance					41	9					5.18
	North Platte	Missing										
	Clay Center			1	1	37	11					5.16
REDLAND	Sidney			13	25	11						3.96
	Alliance			2	11	36	1					4.72
	North Platte			4	26	19	1					4.34
	Clay Center				8	41	1					4.86
NE 78488	Sidney			2	9	19	20					5.14
	Alliance				4	39	7					5.06
	North Platte				2	41	7					5.10
	Clay Center					32	18					5.36
NE 82438	Sidney			4	16	23	7					4.66
	Alliance				7	41	2					4.90
	North Platte					44	6					5.12
	Clay Center				6	41	3					4.94
CENTURA	Sidney			2	8	21	19					5.14
	Alliance				1	43	6					5.10
	North Platte					36	13	1				5.30
	Clay Center					33	17					5.34
SCOUT 66	Sidney			1	15	25	9					4.84
	Alliance				1	43	6					5.10
	North Platte					34	14	2				5.36
	Clay Center				1	45	4					5.06

stature and strong straw to avoid lodging. They must thresh easily and have specific maturity dates which avoid late spring freeze and/or early summer heat. Traits associated with agronomic type have intermediate to high heritability. The agronomic appearance of HRWW has changed greatly since the Turkey variety* was first grown in the Great Plains in 1873. Present wheats are approximately 50 centimeters shorter, 2 to 3 weeks earlier, with vastly improved straw strength.

Biochemical Characteristics

The end use properties affecting milling and baking quality are summarized in Table 1-2 and 1-3. Baking characteristics associated with end use are considered to have intermediate to low heritability (Ausemus, et al., 1967, and Lofgren, et al., 1968). In HRWW those traits that have been significantly improved include, test weight, flour yield, mixing time and tolerance, loaf volume, and crumb grain. Protein percentage has remained essentially constant (Cox and Shogren, 1988). In an effort to preserve previous advances and improve quality, HRWW breeders carefully select parents. Present varieties of HRWW wheat have 25% of their genes in common, tracing back to the parent Turkey (Cox et al., 1986). Much of this common gene pool can be attributed to attempts by the breeders to stabilize and improve quality attributes within HRWW. In a recent study, Cox et al., 1988, compared the genetic contribution for mixing and baking quality of 40 important hard red winter wheats grown throughout the Great Plains from 1919-1988. The experiment was conducted over 2 years and at 6 locations.

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* Variety = cultivar = variety throughout this manuscript.

Table 1-2. 1986 Nebraska Intrastate Nursery Bake Report.

Lab. no.	Variety/ selection	% Flour yield	Mill type	% Protein		% Ash	% mg $KBrO_3$	% Abs.	Bake time	Mixograph		Volume	Ex-ternal	Grain	Texture
				Wheat	Flour					Time	Tol.				
86-842	Bennett	75.6	G	11.40	10.35	.372	.5	63	3 3/4	4	3	905	G-	G-	G-
843	Brule	74.2	G	10.05	8.75	.410	.25	57	6	6 1/3	5-	825	F+	F+	F+
844	Redland	74.5	G	10.30	9.00	.420	1.0	58	5 2/3	5 2/3	5-	860	G-	G	G
845	Cody	74.9	G	10.65	9.30	.382	.25	61	7	7 1/3	5	890	G-	G-	G
846	NE 78488	73.0	G-	10.10	9.60	.388	.0	61	5 1/3	5	5-	870	G	G	G
847	ND 82413	73.5	G-	10.60	9.75	.414	.5	60	4 2/3	4 1/2	3+	865	G-	G	G
848	NE 82419	73.1	G-	10.20	9.05	.376	.25	61	5	5	5-	860	G	G-	G
849	NE 82438	72.8	G-	9.85	9.00	.426	.5	60	7 1/2	7	5	855	G+	G	G
850	Centura	73.0	G-	10.10	9.45	.428	.25	60	5 1/4	6	5-	855	G	G+	G+
851	Scout 66	75.1	G	11.45	9.90	.404	.75	61	3 1/3	3 1/4	3+	865	G-	G-	G-
852	Colt	74.7	G-	10.75	9.60	.364	1.0	60	3 2/3	4	3-	910	G+	G	G
853	NE 82533	71.8	F+	10.35	9.30	.362	.5	59	6 1/4	6 2/3	5-	830	G-	G-	G-
854	NE 82565	72.9	G	9.85	9.10	.382	.5	59	5 2/3	4	4-	855	G-	VG-	VG-
855	NE 82652	72.6	G	10.70	9.15	.384	.5	58	4 2/3	5 2/3	4-	840	F+	G+	G+
856	NE 82656	72.8	G	10.30	9.35	.430	.5	60	6 2/3	6	5-	855	F+	VG	VG
857	NE 82658	74.0	G-	10.80	9.75	.430	.5	59	5 1/2	5 2/3	5-	905	G+	G+	G+
858	NE 83404	71.7	G	10.65	9.80	.432	.25	62	5 1/4	4 1/2	4+	880	G-	G	G
859	NE 83406	71.9	G	11.45	9.90	.444	.5	60	4 1/3	5 1/3	5-	820	G-	G+	G+

Table 1-3. Quality Evaluations for the 1987 Kansas Intrastate Nursery.

Kansas Intrastate Nursery Harvested in 1987.*
Hard Winter Wheat Quality Laboratory
mean P = 12.0%.

Lab. no.	Variety	TWT	WASH	WP	FYLD	H	FASH	P	ABS	T	CG	VOL	M	CVOL	CT
87-601	Newton	56.5	1.66	12.6	69.5	6	0.42	11.1	56.4	4.500	S	998	85.69	1071	4.01
87-602	Arkan	56.3	1.68	13.4	69.3	6	0.40	12.0	54.9	4.000	S	983	75.89	983	4.00
87-603	Victory	57.2	1.66	12.7	71.3	7	0.41	11.8	56.4	3.250	S	930	71.53	944	3.17
87-604	TAM-107	56.4	1.54	12.1	72.5	6	0.41	11.0	60.3	4.375	S	1010	88.18	1094	3.85
87-605	KS831374	58.1	1.59	14.1	73.7	7	0.43	12.9	59.9	5.250	S	1111	81.92	1037	5.25
87-606	KS8010-1-4	57.6	1.68	14.0	73.2	7	0.47	12.8	59.0	3.250	S	1007	72.14	949	3.25
87-607	KS8010-1-12	58.0	1.59	13.3	72.8	7	0.42	12.2	59.3	3.750	S	983	74.24	968	3.75
87-608	KS8010-1-20	57.7	1.76	14.6	72.2	7	0.45	13.4	57.0	2.375	S˜	1014	68.65	918	2.37
87-609	KS8010*-34	57.0	1.68	14.0	71.3	7	0.45	12.6	59.2	4.125	S	1035	76.56	989	4.12
87-610	KS8010*-71	55.0	1.79	14.1	67.1	7	0.44	12.6	59.9	4.125	S	1025	75.52	980	4.12
87-611	KS8010*-73	56.3	1.65	12.4	70.8	7	0.43	11.3	57.5	4.125	S	938	76.57	989	3.78
87-612	KS8010*-38	57.0	1.67	14.2	72.1	7	0.45	13.0	59.9	4.125	S	1010	71.00	939	4.12
87-613	KS8010*-72	54.3	1.67	13.0	72.5	7	0.46	11.9	58.6	4.125	S˜	987	77.16	994	4.08
87-614	KS9010*-1-3-2	57.3	1.67	13.5	73.1	7	0.51	12.3	58.9	3.125	S	988	73.98	966	3.12
87-615	KS8010*-1-4-2	59.1	1.60	13.1	74.8	7	0.47	12.0	57.7	3.000	S˜	972	74.67	972	3.00
87-616	KS81580*-10	53.6	1.72	12.4	70.3	6	0.49	11.1	59.0	4.500	Q	915	75.50	980	4.01
87-617	TB-107	55.3	1.69	12.8	70.0	6	0.41	11.5	58.4	2.500	S	955	76.86	992	2.35
87-618	KS84HW196	56.4	1.65	13.2	72.7	7	0.40	11.9	58.3	4.000	S	1045	83.67	1053	3.95
87-619	KS85H22	54.4	1.74	13.1	70.7	7	0.41	11.9	55.9	2.250	Q	965	74.69	972	2.22
87-620	KS85H136	57.3	1.62	12.7	71.6	6	0.42	11.4	58.3	6.125	Q-S	955	77.73	1000	5.68
87-621	KS85H247	57.6	1.66	13.6	71.1	6	0.40	12.2	59.0	5.625	S˜	1005	76.63	990	5.62
87-622	KS85H274	58.6	1.61	13.4	72.8	6	0.39	12.0	56.6	3.625	S	966	74.00	966	3.62
87-623	HA81162	58.0	1.65	13.0	71.2	6	0.43	11.8	59.5	4.125	S˜	1037	83.68	1053	4.03
87-624	Century	57.3	1.80	12.6	69.8	5	0.52	11.2	59.9	4.375	S	974	81.81	1036	3.95
87-625	TAM-200	60.0	1.70	12.6	69.9	5	0.46	11.2	60.4	5.375	S˜˜	1028	88.36	1095	4.86
87-626	Dodge	57.5	1.73	14.0	71.4	7	0.40	12.7	56.2	4.125	S	1015	73.71	963	4.12
87-627	Norkan	58.0	1.66	13.3	73.1	7	0.43	12.4	58.5	4.750	S	1033	77.98	1002	4.75
87-628	BH-122	56.3	1.62	12.8	71.2	7	0.45	11.7	54.9	2.500	S*	953	74.96	975	2.41
87-629	OK83396	55.9	1.73	13.2	69.4	6	0.46	12.1	62.0	3.500	Q	960	72.53	953	3.50
87-630	Siouxland	58.2	1.59	12.9	75.0	7	0.45	11.7	56.9	3.750	Q-S	968	76.68	990	3.61

* All values expressed on a 14% moisture basis.

TWT = Test Weight
WASH = Wheat Ash
WP = Wheat Prot.
YLD = Flour Yield
H = Hardness
S˜ = Open Grain

FASH = Flour Ash
P = Flour Prot.
ABS = Flour Baking Abs.
T = Bake Mix Time
CG = Crumb Grain Score
S˜˜ = Very Open Grain

VOL = Loaf Volume
M = Loaf Volume/Protein Regression
CVOL = Loaf Volume at 12% P
CT = Bake Mix Time Corrected When P<12%
S* = At Least One Loaf Had Superior Grain

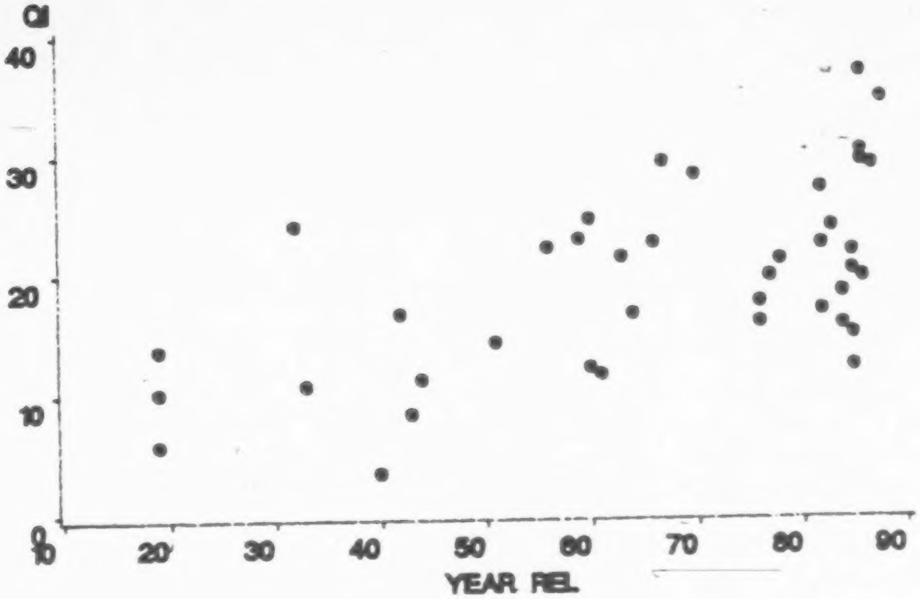
Overall quality of the HRWW class measured as an index of flour protein, mixing time, loaf volume, crumb grain, and texture (12% protein basis) has steadily improved. This improvement is due to the combined efforts of all groups interested in improved quality in the HRWW class. (See Figure 1-1).

Institutional Influences on Plant Breeders

Institutional influences on wheat breeders within the HRWW growing states can vary greatly. The major winter wheat producing states all have plant breeding programs associated with their state land grant universities. Wheat breeders are most influenced by individuals or groups that utilize new wheat varieties, and request information. Some institutional influences are

1. Those with major influence include state agricultural experiment station administrators as they allocate funds from taxpayers, State Wheat Commissions who allocate "check-off" funds for wheat breeding and research, Crop Improvement Associations which provide funds from sales of new wheat varieties, and leading farmers who work closely with and follow the progress of wheat breeding programs.
2. Programs which don't provide funds or very small amounts but still influence decision making include; the Wheat Quality Council, comprised of all segments of the wheat industry; state Associations of Wheat Growers, which provide input concerning farmers needs; the International Grains Program located at Kansas State University, which serves as a sounding board for foreign trade teams and buyers; and competing wheat breeding programs, either public or private, which influence goals and priorities as each breeder strives to produce varieties that will be acceptable to the farmer.

Figure 1-1. Overall Quality Trends in 40 Hard Red Winter Wheat Cultivars Released Since 1919. QI, Quality Index, Equals the Average Rank for Flour Protein, Loaf Volume, Mixing Time, and Crumb Grain When Best Cultivar = 40 and Worst = 1.



As new traits are added to one program and found favorable they are quickly added in competing programs.

3. Institutions with minor influence which provide funds would include private plant breeding companies and sponsored grant programs (USDA or NSF). Plant breeding companies often award grants to public breeders for specific research projects, but rarely support direct varietal development because of obvious competition with private varieties. Grant programs focus on new basic research, and virtually none of the applied research addressed by breeding programs is considered fundable by reviewers.
4. Those groups with some influence which generally do not provide any funds include companies which directly use wheat for bread products, Baking Associations, National Farm Organizations, and the National Association of Wheat Growers.

Serious problems in wheat quality have occurred over the past 50 years. During the 1950's and 1960's the USDA placed discounts on selected varieties perceived to have poor end use quality which were submitted for loan under the Commodity Credit Corporation (CCC). The "discounted variety" label has been deleted from the farm program and CCC.

To improve wheat quality, the USDA established the Hard Red Winter Wheat Quality Laboratory at Manhattan, KS, in 1938 in cooperation with the Kansas Agricultural Experiment Station. Today, this laboratory cooperates with all state and federal breeding programs producing HRWW. In addition all major wheat producing states maintain their own quality laboratories, which interact with the USDA HRWW laboratory.

In an effort to bring all developers and users of HRWW together, the Milling Department at Kansas State University in 1950 accepted advanced breeding lines from the HRWW region which they milled and distributed to collaborators for baking. A meeting was held in Manhattan, KS, to discuss and evaluate end use properties. Results were made available to wheat breeders. A few years later a more formal group was organized and named the Hard Winter Wheat Quality Council. Funding to carry out the work came from flour mills, bakeries, allied trades, and Kansas State University. Reorganized again in 1981 the group is now functioning as the Wheat Quality Council. This group provides a forum for the exchange of information on wheat considered to be candidates for release by either public or private institutions. Today, virtually all HRWW developed for the Southern Great Plains is evaluated by the Council. It has no regulatory power but provides recommendations from mill and baking chemists and university researchers. Meetings of the group help members to be more tolerant of each others views and problems, monitor progress, and form standards for comparison. The results of these efforts have been the systematic improvement of HRWW quality. Today virtually all HRWW varieties grown have acceptable bread baking quality (Finney, 1979). This was not true 20 years ago.

Use of Wheat in Future Traditional Roles

Hard white winter wheats, are being developed in California, Montana and Kansas. In California and Montana, hard white wheats will be grown and sold with "identity preserved", primarily to the far east and Mediterranean regions. Hard white wheat will compete directly with Australian hard white wheat. In Kansas this class is being developed initially for the domestic market. Superior bread baking quality and higher flour yields are specific breeding goals for this class of wheat.

Wheat bred specifically for high amounts of extractable gluten are of interest because wet gluten continues to be in high demand for many products especially in the fast food industry. There will always be a demand for a constant supply of good quality high protein wheat. Industry is initiating several identity preserved programs to maintain a consistent supply of premium quality wheat. An example is the Kansas contract growing of Plainsman V, a high protein, strong mixing wheat. Wheat breeders can and are willing to develop germplasm for a specific use.

Use of Wheat in Future Non-Traditional Products

Wheat bran including the aleurone is removed during milling and sold as animal feed. The aleurone cells are high in non-gluten proteins which have good nutritional potential. Australians have patented a method which separates aleurone protein from finely ground bran.

Uses for enzyme modified gluten (EMG) are currently being researched. The product can be used as a replacement for chemical reducing agents in no-time dough systems which are popular at in-store bakeries.

Chemically modified proteins are awaiting approval for food use by the Food and Drug Administration of the United States. If approved, wheat proteins should find unique uses in the food industry.

Genetic Influence on Wheat Quality

Important end use quality traits, the estimated number of genes thought to control a trait, and the degree a trait is influenced by the environment, can be found in Table 1-4. Environmental variation influences the expression of all heritable traits. Traits whose expression are largely influenced by the environment have low heritabilities, that is, the majority of the variability for that specific trait is due primarily to the environment and not due to genotype. For these traits the only effective way to evaluate performance is to test over numerous locations and years, therefore both quality and yield are evaluated for at least 4 to 5 years at many locations before recommendations are made concerning release.

Functional quality as it is defined and selected for in a breeding program is the interaction of all the traits in Table 1-4 plus many more, including such agronomic traits as shown in Table 1-5. It is impossible to select one trait individually, exclusive of the rest, and interpret final end use quality. Final bread baking quality is the total interaction of all these traits (Finney, 1985). Cereal chemists and wheat breeders use these traits as estimators of end use. If all the traits fall into identified accepted categories, the final product usually is satisfactory.

Interaction Among Grain Yield, Grain Quality and Disease Reactions

Grain yield, grain quality and disease resistance cannot be separated in a breeding program. Each fits into a package that is released as a new variety. Any missing part in this package makes the variety useless to the farmer. Wheat lines are not developed that feature improvements in some traits and the loss of others. Wheat

Table 1-4. Important End Use Quality Traits Utilized in Hard Winter Wheat Breeding Programs, the Estimated Number of Genes Controlling Each Trait, and the Degree to Which Environment Affects the Expression and Variability of That Trait.

Trait	No. of genes	Environmental influence
Physical quality		
Hardness	3 genes	moderate
Color	3 genes	moderate
Kernel size	many	large
Test weight	many	large
Flour yield	many	large
Biochemical quality		
Protein %	few-many	large
Absorption	many	moderate
Mixing tolerance	many	large
Loaf volume	many	large
Crumb grain	many	large
Crumb color	many	moderate
Loaf symmetry	many	moderate

Table 1-5. Mean Summary for Performance and Agronomic Characteristics of the 1987 Kansas Intrastate Nursery Grown in 12 Locations Throughout Kansas.

	Yield[1] bu/a	Test[2] wt.	Protein[3] %	Heading[4] date	Plant ht(cm)	LDG[5]	HF[6]	LR[7]	TS[8]	SB[9]
Tam 2000	55.6	57.6	13.1	125	77	3	S	5MR	8	S
KS8010-1-4-2	55.5	57.5	13.6	124	92	2	S	tMR	3	R
KS8010*-72	55.0	53.5	13.3	125	81	2	R	10S	5	R
TB 107	54.6	54.7	12.9	125	81	8	H	30S	8	R
KS8010-1-4	54.3	56.3	14.1	124	90	3	R	5MR	3	R
KS8010*-34	54.2	55.6	14.1	124	84	2	R	tMR	8	R
KS85H136	54.1	55.0	13.1	129	88	3	R	5MR	8	S
Century	53.9	55.9	13.1	128	81	4	R	5MS	7	S
KS8010*-38	53.8	55.5	14.4	125	83	2	S	5MR	5	R
KS81580*-10	53.0	51.7	13.1	128	90	7	S	tMR	2	S
KS8010*-73	52.5	54.8	13.6	123	75	2	S	tMR	8	R
KS85H247	52.4	56.5	13.7	124	68	4	R	20MR	9	S
KS8010*-71	52.4	54.4	14.5	125	79	2	R	5MS	5	R
Tam 107	52.2	55.1	12.7	122	77	2	S	70S	9	S
KS8010-1-12	51.9	56.7	13.2	123	93	5	R	40S	4	R
Siouxland	51.3	56.4	13.4	126	96	5	S	5MS	5	R
KS8010-1-3-2	51.2	55.2	14.2	125	88	3	R-	10S	4	R
Victory	51.2	55.0	13.7	126	79	4	S	tMR	5	R
KS8010-1-20	50.4	56.2	13.9	123	89	5	R-	5MS	4	R
KS831374	50.2	57.1	14.1	123	79	5	S	10MS	4	R
OK83396	49.0	53.6	14.0	125	71	3	S	10MS	8	S
Newton	49.0	55.5	13.2	127	85	6	S	60S	8	R
KS85H274	48.5	56.6	13.7	124	74	4	R	5MR	9	R
Arkan	47.2	55.2	13.8	124	81	5	R	30S	7	R
Norkan	47.0	56.1	13.8	128	88	4	R	50S	9	R
KS85H22	44.5	52.4	13.5	129	82	4	R	5MR	9	S
Dodge	44.0	55.4	14.3	127	81	4	S	60S	9	R
KS84HW196	44.0	55.2	13.8	125	78	5	S	60S	9	S

[1] Yield calculated from 5.5 m^2 area, bushels/acre
[2] Test weight, 60 lbs/bu standard
[3] Protein 14% moisture basis
[4] Heading, days from January 1
[5] Lodging
[6] Hessian fly rating by Dr. Jim Hatchett: R = resistant, R- = 1 or 2 susceptible seedlings out of 25, H = heterozygous or segregating, S = susceptible
[7] Leaf rust ratings at Manhattan
[8] Tan spot ratings at Hutchinson (1-9 scale)
[9] Reaction to soilborne mosaic virus

diseases, lodging and environmental stress produce shriveled grain which reduces grain yield, lowers test weight, and decreases flour milling yield. The best bread quality wheat is not grown by farmers unless it yields competitively. Yield and quality if evaluated separately as unique entities are usually negatively correlated, primarily due to the negative association between protein percentage and grain yield (Johnson, 1978). Yield and protein content can be increased simultaneously, however, and are not mutually exclusive to one another (Stein et al., 1987, and Heyne 1979).

Genetic Influence on Physical Quality

Kernel size and kernel morphology can be highly influenced by both the genotype and the environment. In Kansas, for example, kernel size can vary from 22 to 45 grams/1000 kernels among varieties (Paulsen et al., 1976). Similar variation can be caused by post-anthesis stress received by the crop. Kernel size and morphology also can be influenced by rate of seeding, injury from disease incidence, and nutrient availability (Paulsen, 1987). Hlynka and Bushuk (1959) summarize information regarding kernel size and weight as it effects test weight.

(a) Kernel size in itself does not influence the weight per bushel.

(b) Density of packing of the grain influences test weight. The shape of kernels and their variation in size may influence the density of packing.

(c) Density of the grain determines bushel weight as influenced by structure and chemical composition, including moisture content.

(d) Thousand-kernel weight (TKW) is affected by average size of kernels and their density. Only density is a factor in weight per bushel. Therefore, TKW and weight per bushel should not have a high correlation.

Genotypic Variability of End Use Quality Traits

Genotypic variability is generally interpreted as the range of expression for a specific trait or traits, i.e., protein can range from 7 to 30% in wheat and its relatives. Bread wheat is a hexaploid species and has a large amount of genetic variability. Landraces and diploid progenitors are additional sources of genetic variability. Genetic variability for any wheat not directly involved in variety improvement programs generally is not measured, however, primarily due to excessive cost. Protein percentage is probably the most frequent quality component measured, and can be improved by crossing with distant relatives of wheat. A practical limit exists, however, because twice as much energy is required to produce a gram of protein in wheat than a gram of carbohydrate (Penning de Vries, et al., 1974). For the future as we begin to understand protein quality it may be more efficient to allow the wheat plant to produce primarily starch and blend in protein to increase the protein percentage of wheat flour. For the present and immediate future, however, primary use of the genetic variability in wheat and its relatives in HRWW programs is to introduce new genes to protect plant health.

Genotype and Environmental Interactions Affecting Quality

Genetic variation, environment, and their interaction add together to affect the final expression of a trait. Genetic x environmental interaction is produced when different genotypes respond differently when grown in different environments. The variety Newton, for example, produces acceptable quality in western Kansas, but is poorer in eastern

Kansas due to susceptibility to disease, in Oklahoma because of late maturity, and in eastern Colorado because of susceptibility to root rots. In many cases, environment can be responsible for greater fluctuations in quality than the varietal reactions (Sears, 1986, and Johnson, et al., 1972). Genotype x environment interaction is of critical importance because most HRWW varieties are grown across a diversity of environments and stable quality performance is the desired product. Measuring a genotype's performance in many variable environments is the only effective method to select stable wheats.

Interactions between physical and biochemical characters are frequent, and usually negative. The most frustrating associations involve protein. High yield and high protein are negatively correlated. This association makes it difficult to improve both traits simultaneously. Protein percentage and protein quality are not correlated (Finney, 1985). It is possible to have extremely high protein and very low quality, the variety Atlas 66 is a good example. Other interactions which affect progress in a breeding program include kernel size x flour yield, and high temperatures at grain filling x weaker mixing tolerance. Susceptibility to diseases and preharvest sprouting both have negative effects on quality. Associations between chromosomes themselves affect quality, e.g., attempts to breed resistance for wheat streak mosaic virus have been unsuccessful because the resistant genes for the disease are closely linked to genes that have a negative affect on quality (Martin, 1987). Lr 19 is a gene that is very effective in preventing leaf rust, and fortunately its linkage with yellow flour color has been broken.

Cultural practices can influence quality tremendously. Nitrogen fertilizer directly affects protein percentage. Planting date and seeding rate affect kernel size. Planting in wheat straw residue increases specific diseases such as tanspot, Septoria, and root rots. Management practices by the farmer can influence quality significantly, and incentives should be directed more toward the producer to ensure better quality.

Genetic Interactions with Storage and Handling

Interactions involving storage and end use are generally considered to be minimal. End use wheat quality can be maintained for a long period if the grain is kept dry and insect free.

Variety Release

The number of varieties grown in commercial production since 1919 are listed in Table 1-6, (Cox et al., 1986). HRWW varieties have increased from 5 in 1919 to 164 in 1984. The number of primary varieties grown in any one year also has increased correspondingly, but appears to have leveled off at approximately 20. Primary varieties account for approximately 90% of the wheat acreage in any year, and about 4 to 6 primary varieties are grown annually in each state.

Quality evaluations in breeding programs usually begin between the F_2 and F_4 generation. Initially samples are measured for milling (micro), kernel hardness, mixing time and tolerance, and protein level. Known check varieties from each growing nursery are tested against the experimental lines. "Check" varieties are used to detect abnormal environmental problems. In addition, checks provide a historical quality data base for the commercial crop of Kansas and the breeding program.

Table 1-6. Number of Cultivars Grown, Number of Primary Cultivars* Grown, and Percentage of Area Covered by Primary Cultivars in the HRWW Regions of the United States.

	Number of cultivars		Percentage of area in primary cultivars
	Total	Primary	
1919	5	1	99
1929	26	4	97
1939	21	10	95
1949	30	15	95
1959	45	16	94
1969	72	21	90
1979	102	19	80
1984	164	20	79

*Those cultivars sown on 1% or more of the total acreage.

In the majority of HRWW breeding programs large scale (Buhler Laboratory Mill) milling and baking evaluations are made at the F_6 generation. Milling yield of flour, bran clean-up, and milling behavior are determined. The flour (100% straight grade) is evaluated for dough mixing, protein, and ash. During the baking test, dough handling properties during fermentation, machining, and panning are observed. Finally the finished baked loaf is evaluated for volume, density, crumb grain, and texture and compared to the nursery checks and a commercial flour which is used each day to validate the baking test, Table 1-1. The objective of the laboratory testing is to release new varieties which are equal to, or better than, the existing commercial wheats.

A final test of each experimental line is coordinated by the Wheat Quality Council. Samples are milled on the pilot mill at the Kansas State University. Flour samples are baked by 30 to 40 collaborators who report data on standardized evaluation forms to KSU milling personnel. In addition, a comprehensive set of laboratory tests are performed on the flour samples. Collaborators meet, discuss results, and a report is published which provides recommendations to wheat breeders regarding the impact of the experimental on the market quality of HRWW.

Release decisions either in public or private programs are made by working committees, usually comprised of experts representing all areas of wheat growth, end use and marketing. A more complete discussion of release procedures can be found elsewhere in this report.

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CHAPTER 2

HARD RED SPRING WHEAT

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CHAPTER 2

HARD RED SPRING WHEAT

Definition of Wheat Quality

Wheat quality can be defined in different ways. Definitions of quality can be given based on the physical traits of the grain, on the biochemical composition of the wheat kernel, or as functional properties related to end use. However, wheat grain quality always refers to specific characteristics of the kernel or processed kernels and not to extraneous non-wheat material present in a parcel of wheat such as foreign material or dockage.

Discussion on the physical, biochemical and functional elements of wheat grain quality follows:

Physical Characteristics of Grain Quality

The various factors under the physical aspects of quality include test weight, 100 kernel weight, shrunken and broken kernels, color, hardness, and heat damaged kernels as well as other types of damaged kernels. Many of the physical parameters are used in the official grading of wheat using the Official United States Standards for Grain (Miller, 1987). Kernel morphology is now of paramount importance in the wheat classification system of the United States. Identification of five principal Classes of wheat is dependent on visual examination of the size, shape and color of the kernels. Three of the five Classes of wheat, have Subclasses. The Subclasses for Hard Red Spring and Durum Wheat are determined by the percentage of dark, hard and vitreous kernels, and hard and vitreous kernels, respectively. Consequently, vitreousness is another important quality trait of a physical nature. In addition to Hard Red Spring and Durum Wheat the other three major Classes are Hard Red Winter, Soft Red Winter and White Wheat. The two remaining Classes are identified as Unclassed and Mixed Wheat.

Licensed grain inspectors consider only the physical characteristics of the wheat and take analytical measurements of foreign material, contrasting classes and wheat of other classes. These factors should not be considered as part of the physical quality of the wheat grain of the predominant class in a parcel. However, very often wheat grain quality has been identified in terms of "cleanliness" of the grain. The grading of wheat is intended only to describe the physical nature of the lot or parcel; wheat grain quality for end use is implied only by the information on predominant Class composition.

Biochemical Characteristics of Grain Quality

The wheat kernel is composed of several biochemical components. The major component is the carbohydrate starch in the endosperm, yet the protein also in the endosperm is considered from farmer to end use processor to be the most important component in hard red spring wheat quality. The biochemical components primarily influence the functional properties to be discussed in the third definition of quality. The quantity and quality of protein present in flour milled from hard red spring wheat are the most important factors in end use quality. Protein in wheat, however, is not a homogeneous entity. Traditionally, wheat proteins have been classified into four types according to their solubility (Hoseney, 1986). These four types include the albumins, globulins, gliadins and glutenins. The latter two are responsible for the formation of gluten, the protein complex, that is so important in determining the dough and baking properties of hard red spring wheat flour. Unfortunately protein classification based on solubility does not define wheat protein completely. Techniques such as electrophoresis, isoelectric focusing, gel filtration and other procedures are being used to further characterize and identify the various protein components.

The high quality and quantity of protein of hard red spring wheat are the characters designating it as a wheat suitable for blending with other wheats to improve quality for breadmaking. The starch content of wheat and flour is, in general, inversely related to protein content (Pomeranz, 1971) and therefore is higher in flours from soft wheat than in those from hard wheat. Starch has a role in dough mixing and baking and is primarily responsible for the bread staling process. Changes occurring in the starch as bread is allowed to age causes the crumb to become firmer, consequently an increase in staling. The structure and composition of the starch granule as related to end use has been the subject of many books.

Although a minor component, lipids (fatty substances) compose 2 to 3% of wheat and wheat flour. Lipids have been studied extensively and represent a complex group of chemical compounds (Pomeranz, 1971). Some lipids have been shown to have a specific function in bread baking.

Other minor components of hard red spring wheat flour are the pentosans (2 to 3%) which have been studied extensively regarding structure and end use. The pentosan component in flour contributes to water absorption in baking because of its high water binding capacity.

Enzymes in wheat flour such as the proteases and amylases can affect dough and bread properties. When the amylase enzyme content becomes excessive which occurs with sprouted wheat, the baking quality is affected.

The various interactions that occur with the biochemical components are important when doughs are produced thereby contributing to the quality of the final bread product.

Functional Characteristics of Grain Quality

Functional quality in hard red spring wheat can be divided into four different areas: quality with regard to (1) the kernel of wheat, (2) milling performance and flour quality, (3) physical dough properties, and (4) baking properties.

Wheat Kernel Quality

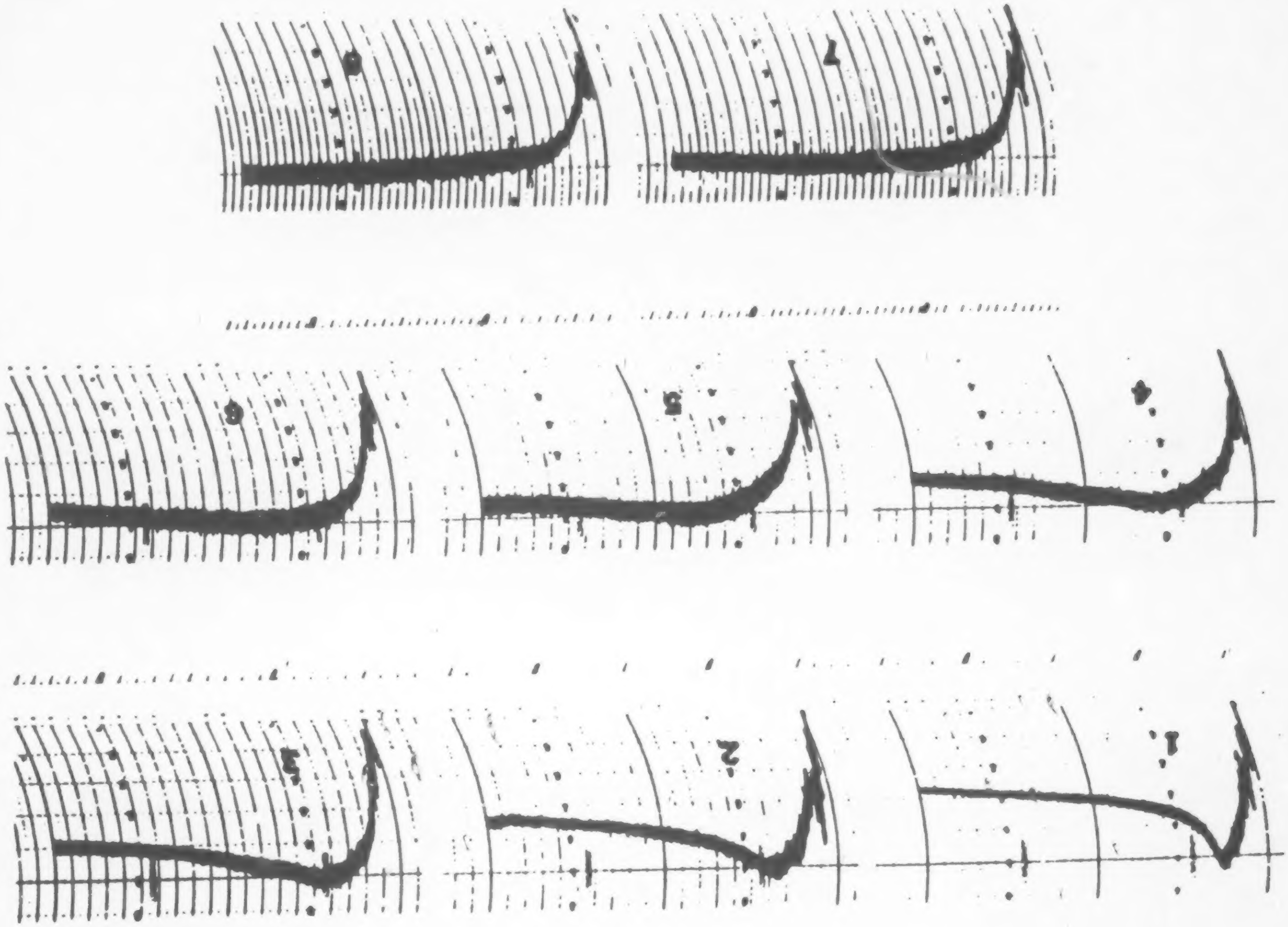
1. Test weight, that is, weight per unit volume, is important as an indicator of flour extraction.
2. Protein percentage is very important because the quantity and quality will affect dough properties and bread baking performance.
3. Amylase activity, usually measured by the falling number method, which increases with sprouting can affect dough properties and bread performance.
4. Weight per 1000 kernels is considered as a good indicator of flour extraction percentage.
5. Vitreous kernel content will affect the Subclass of some wheat Classes including Hard Red Spring Wheat.
6. The moisture content of the wheat will affect storeability and handling of the grain.

Milling and Flour Quality

1. The conditioning of the wheat and its flow pattern through the mill are important in the milling operation.
2. The total flour extraction should be as high as possible.
3. The flour color should be a bright creamy color and not grey or dull and should be free of specks.
4. A low flour ash content is desirable.
5. Flour protein percentage for Hard Red Spring wheat should be high because of the manner in which this wheat class is used. The drop in protein percentage from the wheat to the flour should not be greater than one percentage unit.
6. Wet gluten content should be high when compared to other classes of wheat.
7. The flour should contain some amylase enzyme. Excessive amounts, however, which are present in badly sprouted wheat are detrimental in baking.
8. Some damaged starch (physical damage of the granule as a result of the milling operation) in the flour is beneficial to the baking process whereas excessive amounts can be detrimental.

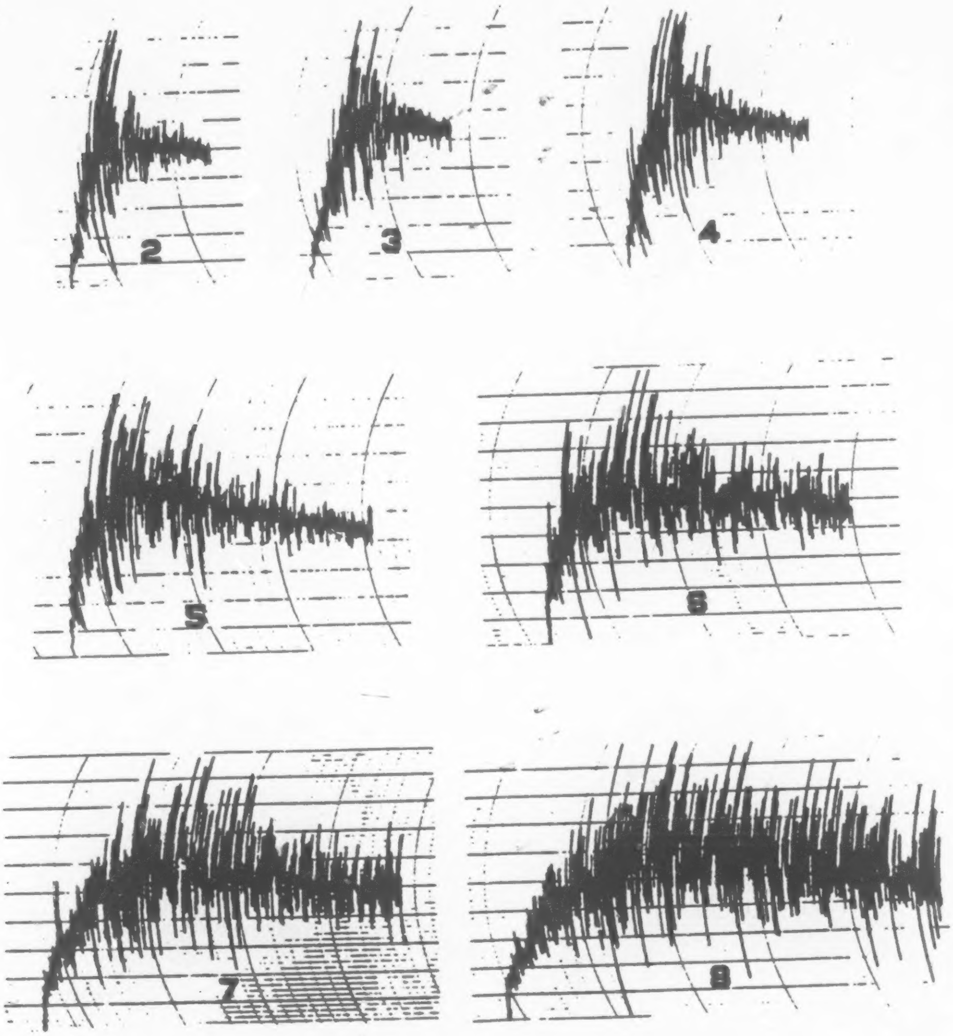
Physical Dough Properties. Various instruments are used to assess the physical dough properties of flour samples including the farinograph, mixograph, extensograph and alveograph. These instruments are of the dynamic or static type. The dynamic type make a measurement on the dough as it is being mixed (farinograph and mixograph) while the static type make a measurement on a dough at rest (extensograph and Alveograph). Figures 2-1 and 2-2 show the range in type of mixing curves

Figure 2-1. Reference Farinograms for Hard Red Spring Wheat.



Source: Department of Cereal Science and Food Technology, North Dakota State University.

Figure 2-2. Reference Mixograms for Hard Red Spring Wheat.



Source: Department of Cereal Science and Food Technology, North Dakota State University, Fargo, ND.

obtained from flour-water doughs using the farinograph and mixograph, resp. A 1 rating represents a weak dough, an 8 rating a very strong dough. Some of the quality information from flour milled from hard red spring wheat which can be obtained from these instruments includes the following:

1. Absorption or the amount of water required to produce a dough of a definite consistency.
2. The mixing time or the time required to develop the dough to its optimum.
3. The tolerance of a specific dough to overmixing. A relatively high value is desirable because of the mechanical abuse to which the dough is subjected during commercial mixing.
4. The extensibility and resistance to extension of a dough which provides a measure of the gluten quality.

Bread Baking Quality. The term bread when used in conjunction with hard red spring wheat flour quality refers to the production from the mixing of flour, water, yeast, salt, sugar and other miscellaneous ingredients to a homogeneous mass and subjecting the mixed dough mass to fermentation prior to shaping and baking.

1. The baker desires a flour which requires a high water absorption to produce a loaf of bread, as bread yield will be increased.
2. A relatively short mixing time but with good tolerance is desirable. A short mixing time is desirable to minimize work input and the time to develop the dough.
3. The dough should be such that it will machine without difficulty and have good fermentation tolerance.

4. The final loaf of bread should have good volume, satisfactory external appearance including crust color, and desirable internal characteristics including grain and texture and crumb color.

Objectives of Genetic Selection

Physical and Functional Characteristics Related to Grain Quality.

The main characters controlling quality of hard red spring have been discussed previously under definition of wheat quality. These characters long have been recognized and improved by genetic selection.

Biochemical Characteristics Related to Grain Quality

Protein Quantity and Quality.

The protein of all the various biochemical components found in hard red spring wheat will have the greatest effect on the bread end product. Gluten formed when flour is mixed with water and other ingredients to form an elastic dough is the key material to make a loaf of bread. The gluten which is primarily protein will determine mixing and dough handling properties, to a large extent water absorption, and also the bread characteristics including loaf volume and external and internal properties.

Carbohydrates.

Carbohydrates are major components of wheat and wheat flour and include the sugars, the glucofructans, the pentosans and starch (D'Appolonia, 1976). Carbohydrates have specific functions in physical dough properties as well as in bread baking.

The sugars in flour serve as a nutrient source for the yeast during the fermentation stage, and contribute to the desired brown crust color of the baked loaf of bread.

The major role of the glucofructans also is as a nutrient for the yeast during fermentation.

Although the literature contains conflicting reports on the exact role of pentosans in baking, they appear to influence loaf volume perhaps as a protein-pentosan complex. Their ability to bind considerable water is well documented thus contributing to increased water absorption in bread systems.

Starch is the most abundant biochemical constituent in wheat flour. The starch exists in the form of distinct granules and damage to the granules during the milling process can affect dough properties and the resultant bread. A moderate amount of damaged starch is beneficial but excessive damage is undesirable since bread quality including loaf volume will be adversely affected. Starch is involved during the mixing, fermentation and baking stages of bread production. In addition, changes occurring in the starch during bread storage are the major contributor to the bread staling process as discussed previously.

Lipids. The lipids found in wheat are quite complex because they are composed of many different chemical classes and within each class there are a large number of individual compounds. The effect of different wheat flour lipids on bread baking quality has been reported by numerous workers. The addition of shortening or fat (lipid) in the bread formula exerts a physical action rather than a chemical one in the baking process.

Enzymes. Wheat contains numerous enzymes including amylases, proteases, lipase, phytase, and lipoxygenase each of which can affect dough and bread properties in a different manner.

Vitamins and Minerals. Wheat, wheat flour and bread are important sources of such vitamins as thiamine, niacin, riboflavin, pyridoxine, pantothenic acid and tocopherol. In addition they are a good source of several minerals.

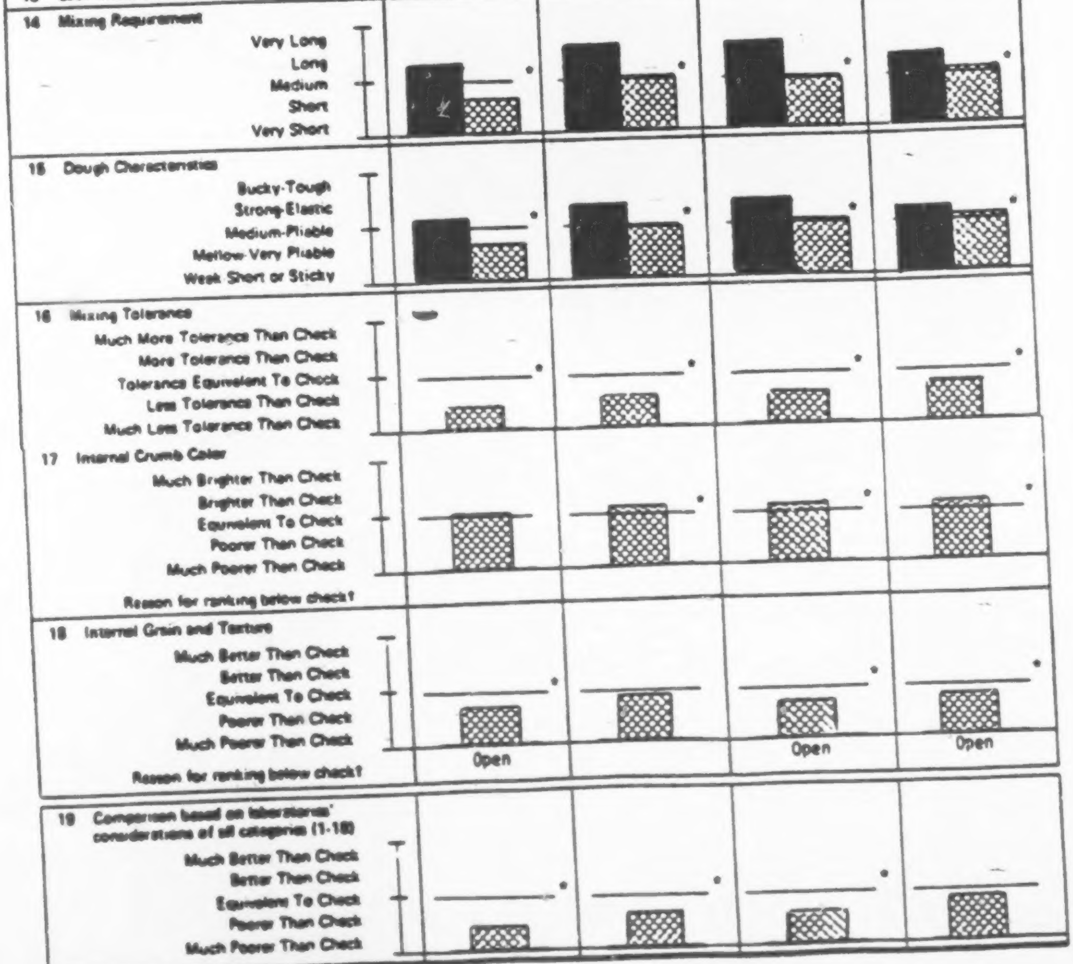
Institutional Influences on Genetic Selection for Quality

Although there are various institutional influences on genetic selection for end use quality for the various wheat classes, both the domestic and foreign end use manufacturer will dictate what is needed in a flour to make a specific product. Flours are milled from wheat lots usually composed of grain from several varieties produced under similar or somewhat variable conditions and composited at the country elevator. Wheat from country elevators goes directly to millers or is composited further with "like kinds" at terminal elevators. Flours having variable characteristics are blended by the miller to meet the specifications of the domestic baker, occasionally a foreign buyer, or other flour users. Most foreign buyers purchase wheat and mill to flour to fit their specific requirements. The reputation that hard red spring wheat (known as Dark Northern Spring Wheat in the export market) enjoys has resulted because of the demand for a blending type wheat in certain importing countries. Consequently, genetic selection has been based on providing cultivars with quality providing this blending capability. Hard red spring wheat also is used for specialty type products so there is a need in genetic selection to provide cultivars to meet the requirements for such products. The situation is similar for the other wheat classes.

The needs of the end user can be made known by various means, including among others, the Wheat Quality Council, Spring Wheat Quality Advisory Council (see Figure 2-3), State Wheat Commission or Councils,

Figure 2-3. Summary Results of Cooperating Laboratories of One Experimental Grown at Four Locations Compared to the Check.

Location	Minot		Redfield		Casselton		Crookston	
Variety	Check	M-2	Check	RF-6	Check	CA-12	Check	CR-17
1 Wheat Protein %	15.1	13.1	14.8	14.0	14.8	13.5	15.8	14.7
2 Flour Protein %	14.0	12.2	13.7	12.7	13.6	12.2	14.8	13.9
3 Test Weight	62.1	62.9	60.5	61.3	58.2	58.5	60.4	60.0
4 1000 Kernel Weight (Grams)	36.4	35.2	27.9	28.7	30.9	30.9	27.4	27.1
5 % Large Kernels	61	47	26	15	41	26	19	10
6 % Small Kernels	1	1	5	4	2	3	4	6
7 Wheat Ash %	1.70	1.61	1.71	1.72	1.77	1.77	1.79	1.88
8 Flour Extraction %	70.90	68.14	68.02	64.75	69.14	67.44	67.70	67.43
9 Flour Ash %	.39	.35	.39	.34	.39	.34	.47	.44
10 Pounds 0.46% Ash Flour per cwt. wheat	76.95	77.50	74.70	73.80	74.95	75.10	66.50	74.35
11 Farinograph: Absorption %	65.5	62.7	61.8	61.8	61.6	60.5	63.6	62.8
Arrival Time	6.5	3.5	4.5	5.5	3.5	4.0	5.0	5.0
Peak	11.0	5.0	15.5	8.0	10.0	8.0	9.5	8.0
Stability	13.0	4.5	15.5+	9.0	16.5+	9.5	12.0	8.0
M.T.I.	15	40	5	15	5	30	25	20
12 Bake Absorption (14% M.B.)	64.8	62.0*	62.3	61.8	62.6	60.7*	64.2	63.1*
13 Loaf Volume (% of Check)	100	94.8*	100	98.3	100	100.7	100	100.3



*Difference is statistically significant at the 5% level.
†Most frequently reported comment.

Source: 1986 Spring Wheat Quality Advisory Council Program Report.

U.S. Wheat Associates, trade team delegations visiting the United States, and other promotional type organizations.

The wheat variety is the finished product of wheat breeding. The sources of funding used to undertake plant breeding programs may have an influence on genetic selection but concommitantly there must be a market for the raw material. When farm programs have encouraged yield as a primary objective in some years, HRSW producers may have opted to sacrifice quality for high yielding varieties unless there was an incentive to grow high quality cultivars to receive protein premiums.

In the final analysis the consumer is the one who will accept or reject a specific product, thereby indicating the need for wheats with certain qualities.

Genetic Influence on Wheat Quality

Characters Under Genetic Control

The major characters controlling quality of hard red spring (HRS) wheat have been listed previously. These characters are under genetic control and are affected variably by environmental factors (Hehn and Barmore, 1965). Wheat characters may be classified for type of inheritance ranging from highly qualitative to highly quantitative. Highly qualitative characters are simply inherited (controlled by 1 to 3 genes) with minimum environmental influences, and highly quantitative characters are multigenic with large environmental effects. Classification of a character may differ based on the germplasm investigated, the environment tested, and the experimental procedure and evaluation employed. Genetic improvement strategies and breeding procedures for a character are influenced by type of inheritance.

Genetic progress generally is slower and more difficult for a quantitative character.

Most of the physical characters such as test weight, kernel size and morphology, kernel hardness, and kernel size distribution are quantitatively inherited. Kernel weight has been reported both as simply inherited (Sharma and Knott, 1964) and has shown selection response as a multigenic character (Busch and Kofoid, 1982). Studies of kernel texture or vitreousness have indicated qualitative (Aamodt and Torrie, 1935) and quantitative inheritance (Davis et al., 1961). Expression of yellowberry or starchiness of areas in the kernel endosperm is determined genetically but is influenced strongly by environmental factors (Sallans and Simmonds, 1954), and is related to nitrogen metabolism within the wheat plant (Henson and Waines, 1983).

Qualitative inheritance has been reported for biochemical characters of HRSW and HRWW only for wheat protein percentage (Haunold et al., 1962; Cowley and Wells, 1980) and for gluten strength (Ausemus et al., 1946). However, a predominance of the literature reports quantitative inheritance for wheat protein (Davis et al., 1961; McNeal et al., 1972; Halloran, 1981; Loffler and Busch, 1982), and for gluten strength (Lebsock et al., 1964; Hehn and Barmore, 1965). Analyses of endosperm proteins in wheat indicate that specific high-molecular weight subunits of glutenin are simply inherited and offer potential as a new technology to breed for improved wheat protein (Bietz, 1987). Other biochemical characters are quantitative because of multigenic inheritance or genetic and environmental interactions.

Functional end use characters are considered quantitative because they are the result of the interaction of many biochemical characters and environmental effects.

Interaction of Grain Yield-Quality-Disease

Specific breeding objectives of a HRS wheat breeding team include about 20 agronomic characteristics and 20 characters controlling quality. Breeding strategies and procedures become complex as the breeding team attempts to combine improved levels of all these qualitative and quantitative characters in one adapted cultivar. Total genetic progress is slow and each new cultivar usually represents an improvement in only several characters compared to previously released cultivars. New cultivars are not perfect. Frequently some compromises are made in characters as the total worth of a potential cultivar for commercial production and product end use is considered prior to a release decision. Some characters such as wheat stem rust resistance are indispensable and may not be compromised.

An increase in potentially fertile florets of the spike (head of wheat) has contributed to grain yield advances in wheat but increased variation in kernel size has resulted (Simmons, 1987). This more variable kernel size distribution negatively influences some milling properties, but the character has been compromised somewhat to achieve improved genetic potential for grain yield.

Increased grain yield and grain protein percentage are major breeding objectives in HRS wheat; however, these two characters are inversely related (Davis et al., 1961; McNeal et al., 1972; Loffler and Busch, 1982). This negative correlation has hindered progress in the simultaneous genetic improvement of grain yield and grain protein percentage in the bread wheats. Grain protein percentage may be compromised slightly in high yielding cultivars but certain minimum requirements are essential for the domestic and export markets of HRS wheat.

Genetic resistance to the stem and leaf rust diseases of wheat is a long term goal of spring wheat breeding programs to minimize the potential for yield and quality losses (Johnston, 1967; Schafer, 1987). Widespread distribution and dissemination, pathogen variation, and potential for devastating epidemics and losses make stem rust resistance a necessary character of spring wheat. Stability of wheat production and quality, and the avoidance of pesticide use result from the "built-in" genetic, i.e., biological, resistance to stem rust. The foliar and head blights are other wheat diseases that are less widespread but may cause local severe losses in grain yield and quality (Cunfer, 1987). Several of these diseases are _Septoria_, tanspot, and scab. Severe localized outbreaks of the insect pests, wheat stem sawfly and Hessian fly, cause losses of wheat yield and quality (Hatchett et al., 1987). Cultural practices and the wheat host resistance restrict or limit levels of the pest populations.

Genotypic Variability

Wheat and related _Triticum_ (wheat) species have not been investigated adequately to determine the range of available genetic variation and to identify the appropriate breeding procedure for each of the characters controlling quality. Wheat germplasm collections have been evaluated _primarily for agronomic characters but not for characters controlling quality._ Evaluation of wheat germplasm collections for end use quality is needed and desirable. However, public and private laboratories now evaluate all samples possible from breeders, and probably breeders would choose the evaluation of more breeding samples rather than the end use quality of individual entries in germplasm collections.

Genetic variation is essential for the breeding improvement of a wheat character such as grain protein percentage. Numerous studies have indicated potential sources of genetic factors for grain protein percentage (range of 8 to 20% on a 14% grain moisture basis) but limited breeding information (Watson et al., 1966; Chapman and McNeal, 1970; Vogel et al., 1973; Diehl et al., 1978; Kramer, 1979; Loffler and Busch, 1982; Grama et al., 1983). Some germplasm may have high grain protein percentage because of nonadaptation resulting in shrunken, abnormal kernels; however, other germplasm with desirable genes for grain protein percentage, if the kernels developed normally, may not be identified because of poor adaptation. Certain breeding and selection procedures are more effective for the use of unadapted germplasm (Loffler and Busch, 1982; Eaton et al., 1986) and for the use of alien germplasm (Knott, 1987). Some germplasm sources of high protein may be undesirable such as 'Nap Hal' because much of the increased protein is in the bran rather than in the endosperm (Vogel, 1974).

The use of genetic factors derived from related species of wheat may create undesirable genetic variation of wheat quality. A certain chromosome segment of rye has been translocated to the wheat chromosome 1B. This translocation (known as 1B/1R) carries genes for excellent resistance to the wheat diseases, leaf rust, stem rust, stripe rust, powdery mildew, (Mettin et al., 1973; Zeller, 1973). The 1B/1R translocation has been used extensively in wheat breeding programs but recently has been associated with poor bread making quality, specifically dough stickiness as a result of high speed mixing or slightly overmixing (Law and Payne, 1983; Martin and Stewart, 1986).

Interactions With Genotypes

Expression of most wheat characters controlling quality is the result of the wheat plant genotype interacting variably with other factors, primarily environmental and production management. Wheat breeding programs usually are funded and located for the development of cultivars adapted to a certain geographical region. Wheat cultivars may be developed for specific adaptation (more narrowly defined environmental and management requirements) as opposed to broad adaptation to a wider range of environments and management practices. That is, a breeder develops HRSW cultivars for North Dakota or special ecozones of North Dakota.

Numerous examples are available of the effect of genetic X environment interactions on wheat quality. The wheat plant growing in the field is especially sensitive to drouth or heat stress at flowering time, and to foliage disease infection during high humidity periods before and after heading. Interactions pertinent to dryland production of HRS wheat are how the differential response of wheat genotypes to post-anthesis drought, high air temperature and other environmental factors, affect grain yield, kernel weight, test weight and other grain characteristics including end use performance. (Wiegand and Cuellar, 1981; Bruckner and Frohberg, 1987). Wheat genotypes respond differently to environmental conditions for nitrogen remobilization and redistribution within the plant thus influencing grain protein percentage (Simmons, 1987). Favorable environmental (climatic) factors contribute to the incidence of stem rust which reduces grain yield and quality (Schafer, 1987).

Genetic X management practice interactions affect wheat quality. Nitrogen fertilization of the growing wheat plant increases grain protein, thus the milling and baking quality of bread wheats is improved (McGuire et al., 1974). However, excess nitrogen fertilization may cause lodging resulting in shrunken grain, grain sprouting, and high α amylase content. A planned nitrogen (N) fertilization program is needed to optimize grain yield and protein percentage (Goos, 1984), and avoid nitrogen movement in the soil which enters groundwater. Genetic variation for uptake, assimilation, remobilization, and translocation contribute to a genetic X fertilization interaction for grain protein percentage (Simmons, 1987). Conservation soil tillage practices and crop rotations that are favorable to the survival and reproduction of insect pests such as the wheat stem sawfly and the Hessian fly necessitate the production of resistant wheat cultivars (Hatchett et al., 1987). Insect injury and damage reduces grain quantity and quality of susceptible cultivars. Irrigation and variable harvest procedures (e.g., swathing prior to threshing versus straight combining without swathing), are additional management practices that may cause differential genotype responses for grain quality.

Genetic X grain handling and storage interactions are not a present problem if the grain of HRS wheat is harvested and stored at safe moisture content in clean, dry bins free of insect contamination with periodic monitoring for grain condition to preserve grain quality.

Breeding for Specific Markets

Improved cultivars of HRS wheat are bred for use as blending wheats to produce bakery flours, and for use to produce specialty flours for hearth breads. These high protein, high quality cultivars produce a commercial crop that is in demand for both domestic and export markets.

A Flow Chart or Discussion of Breeding a HRSW Variety

Populations of wheat segregating for genetic characters are developed to select agronomically improved genotypes for release as new cultivars. The breeding procedures used vary among breeding programs but the basic objective is to select for highly heritable characters, i.e., plant height and maturity, disease resistance, in early generations and to select for more complexly inherited characters, i.e., yield, and adaptation, in later generations. Individual plants and small progeny rows are evaluated during genetic segregation and when seed supply is limited. When genetic stability and uniformity are achieved and seed quantity is increased, then the genotypes (wheat lines) that are retained from early selection are evaluated more extensively in larger replicated plots over environments (locations and years). Data for such end use quality and agronomic characters are shown in Tables 2-1 and 2-2, resp. These data are used on a continuous basis by breeders for selection and to establish the superiority of an advanced experimental wheat line. The breeding team proposes a selected wheat line to the official variety release committee for consideration to release as a new variety (cultivar). The release committee considers the potential value of the variety based on such data as shown in Tables 2-1 and 2-2. Usually more agronomic data (locations and years) are considered, but the minimum number of tests may vary among release agencies.

Hard red spring wheat varieties released in the United States, 1978-1987, are listed in Table 2-3.

Table 2-1. Analytical, Milling and Baking Data Comparing ND 606 Experimental Wheat to Various Hard Red Spring Wheat Varieties. (3 Year Average, 23 Locations)

										FARINOGRAM				3 HOUR FERMENTATION							
					PROTEIN 14% MB					PEAK MIX					MIX		LOAF				
VARIETY OR NUMBER	YLD BPA	TEST WT LB/BU	VIT KER %	WHT FAL NO SEC	WHT %	FLR %	FLR EXT %	WET GLU %	FLR ASH %	TIME MIN	TOL MIN	MTI BU	CLASS	ABS %	TIME MIN	DO	VOL CC	G-T	CD CL	CT CL	SYM
ALEX	48.3	60.0	83	440	15.5	14.9	67.6	40.0	0.47	12.8	16.2	21	6.3	67.4	2.65	10.0	942	8.2	8.5	10.0	9.9
APEX 83	48.0	59.0	52	390	14.4	13.7	70.6	33.1	0.46	16.3	15.0	21	6.6AD	62.7	3.60	9.9	860	7.9	8.6	10.0	9.1
BUTTE 86	48.5	59.8	76	442	15.3	14.3	67.7	39.5	0.44	11.1	12.3	29	5.5	70.2	2.80	10.0	887	8.3	8.4	10.0	9.7
CHALLENGER	47.8	59.3	57	397	14.6	13.9	71.0	33.9	0.46	16.0	15.9	19	6.7AD	62.6	3.75	9.9	877	8.0	8.6	10.0	9.1
COLUMBUS	44.9	59.2	81	476	16.3	15.4	69.2	44.2	0.48	8.5	10.8	27	5.3	69.0	2.80	10.0	927	8.2	8.2	10.0	9.8
GUARD	49.0	59.3	68	419	14.9	14.0	67.6	35.4	0.46	13.8	17.2	19	6.3	66.6	3.70	10.0	903	7.9	8.4	10.0	9.5
LEN	47.2	59.0	81	417	15.5	14.7	69.1	37.8	0.48	13.4	15.9	19	6.9	68.5	3.30	10.0	951	8.3	7.8	10.0	10.0
MARSHALL	49.9	59.0	75	420	14.6	13.8	70.5	38.0	0.45	8.8	11.8	27	5.1	64.1	2.00	10.0	879	7.9	8.1	10.0	9.3
ND606	52.4	59.7	81	426	15.3	14.3	68.4	40.6	0.44	10.5	13.0	27	5.6	68.8	2.85	10.0	935	8.1	8.4	10.0	9.9
STOA	52.0	59.1	79	419	15.5	14.7	68.3	39.5	0.44	13.7	16.0	18	6.8	68.2	2.75	10.0	944	8.3	8.4	10.0	9.9
SUCCESS	49.6	58.4	68	411	14.8	14.0	69.7	36.6	0.49	10.7	13.1	25	5.7	67.0	2.10	10.0	935	8.2	8.7	10.0	9.8
WHEATON	52.9	57.8	71	414	14.4	13.5	70.0	34.3	0.48	14.3	14.1	21	6.3	66.1	2.95	10.0	915	8.1	8.4	10.0	9.6
2369	49.9	59.9	64	424	14.9	14.0	69.1	34.0	0.44	18.2	19.4	17	7.0	64.7	3.85	9.9	882	8.0	8.6	10.0	9.0

Yield - Bushels/Acre
Test weight - pounds/Bushels
Vitreous Kernel, %
Wheat Falling Number, seconds
Wheat Protein, 14.0% Moisture Basis
Flour Protein, 14.0% Moisture Basis
Flour Extraction, %
Wet Gluten, %
Four Ash, %

Peak Time, Minutes
Mixing Tolerance, Minutes
Mixing Tolerance Index, Brabender Units
Farinogram class

Baking Absorption, %
Baking Mix Time, Minutes
Dough handling properties
Loaf Volume, cc
Grain and Texture
Crumb color
Crust color
Symmetry

Source: Hard Red Spring Wheat Quality Report, Department of Cereal Science and Food Technology, North Dakota State University, Fargo, ND.

Table 2-2. Summary of Agronomic Performance of Entries in the 1986 Hard Red Spring Wheat Variety Trial at North Dakota Agricultural Experiment Stations.

Variety or line	Headed days	Height cm	Lodging Score 0-9	% Rust		Leaf Score 0-9	Shattering %	Test Weight lbs/bu	Yield,bu/A	
				Leaf	Stem				86	85-86
	(7)	(7)	(6)	(4)	(1)	(4)	(1)	(8)	(8)	(16)
Waldron	52	90	2.1	40S	5R	7.1	0	56.7	34.4	40.8
Olaf	55	78	0.7	30S	tR	6.1	Tr	57.6	40.8	--
Butte	51	83	2.9	40S	0	6.6	0	59.6	44.6	48.1
Coteau	57	94	1.9	5MR	0	4.5	Tr	58.5	41.9	43.8
Len	54	78	0.8	5MR	0	5.8	0	57.3	40.7	46.1
Alex	54	89	2.9	5R	30MR	6.1	0	58.2	43.1	47.4
Marshall	55	75	0.8	20MS	tR	5.1	0	58.5	49.1	51.0
2369	53	76	1.0	20S	0	5.8	0	59.2	48.3	50.5
Columbus	56	97	1.8	20MR	0	5.5	0	58.8	43.1	46.1
Guard	51	73	1.1	5MR	5R	6.3	0	58.2	44.3	48.6
Challenger	51	72	1.2	20MS	0	5.8	0	58.0	44.1	47.7
Wheaton	54	72	1.1	5R	0	5.1	0	56.5	48.5	53.5
Stoa	53	88	1.4	tR	0	5.6	0	58.3	49.6	52.4
Katepwa	54	93	3.4	30S	0	6.7	0	58.2	43.4	46.8
Apex 83	51	70	1.1	20MS	0	5.8	0	58.2	39.8	46.6
Success	57	84	1.5	5R	0	4.8	0	57.1	44.9	49.8
Norak	53	73	0.8	tMR	0	5.1	0	58.5	48.6	53.0
Leif	54	79	1.1	5R	0	4.5	0	58.9	49.2	51.7
747	50	70	2.5	55S	20MS	7.0	0	56.3	40.8	46.0
HY320	55	76	2.3	20MS	10MR	5.8	0	55.2	43.5	50.0
Celtic	53	78	0.7	5MR	tR	5.6	0	58.2	44.8	49.8
Butte 86	51	81	1.4	10MR	0	5.4	0	59.8	49.6	50.3
Kenyon	54	91	3.3	tR	tR	5.6	0	58.0	45.1	--
Nordic	54	78	1.5	10MR	0	5.1	0	59.4	54.4	--
Telemark	53	70	0.2	tMR	0	5.6	0	57.3	45.9	--
SD8026	50	84	3.2	5MR	0	5.8	10	58.9	47.2	48.3
SD2956	53	78	0.8	tMR	0	5.8	0	58.7	51.0	--
ND606	53	89	2.2	tR	0	4.5	0	58.8	50.6	53.8
ND617	54	79	1.0	tR	tR	6.5	Tr	59.5	46.9	51.2
ND618	53	80	1.0	5R	0	5.3	0	57.6	46.5	50.0
ND624	54	88	1.6	20MS	tR	5.2	0	59.8	55.2	--
ND625	55	89	1.8	5R	0	4.6	0	58.4	49.5	--
ND626	52	80	0.9	5MR	0	5.5	0	59.6	49.2	--
ND627	53	81	1.4	5MR	tR	6.6	0	58.6	48.2	--
ND628	56	80	0.4	tMR	20MR	4.4	0	57.2	52.6	--
ND629	57	82	0.8	tR	tR	5.1	0	57.7	47.7	--

Source: 1986 Annual Report of R. C. Frohberg, Wheat Breeder, Agronomy Department, North Dakota State University, Fargo, ND 58105.

Table 2-3. Year of Release, Name, and Origin of Hard Red Spring Wheat Varieties, Public and Private in the United States Only, Over the 10 Year Period, 1978-87.

Year	Cultivar name	Origin
1978	Angus	ARS & MN AES
	Coteau	ND AES
	James	SD AES
	Powell	UT AES
	Shasta	CA AES
	Solar	Agsco
1979	Len	ND AES
	PRO Brand 771	Northrup King
	Wampum	WA AES
	Westbred Aim	Western Plant Breeders
	Westbred 906R	Western Plant Breeders
1980	Marberg	ARS & MT AES
	Oslo	Nickerson American Plant Breeders
	Pondera	ARS & MT AES
	PRO Brand 711	Northrup King
	PRO Brand 751	Northrup King
	Tracey	World Seeds
	Walera	Agsco
	Westbred 911	Western Plant Breeders
1981	Alex	ND AES
	PR2360	Pioneer
	PRO Brand 715	Northrup King
1982	Centa	SD AES
	Erik	Nickerson American Plant Breeders
	Marshall	ARS & MN AES
	PR2369	Pioneer
	WM99	Weathermaster
	Wynne	UT AES

Table 2-3. (Cont.)

Year	Cultivar name	Origin
1983	Apex 83	Seedtec
	Challenger	Western Plant Breeders
	Courtney	World Seeds
	Guard	SD AES
	McKay	ARS & ID AES
	Victory 283	Dakota Oat
	Wheaton	ARS & MN AES
	Yolo	CA AES
1984	Anza	CA AES
	Buckshot	Arrowhead
	Glenman	MT AES
	Leif	Rohm & Haas
	Norak	Seedtec
	Norseman	Nickerson American Plant Breeders
	PR2348	Pioneer
	Stoa	ND AES
	Success	Cenex
1985	Celtic	Nickerson American Plant Breeders
	Inia 66R	CA AES & CIMMYT
	Portola	CA AES & CIMMYT
	Tammy	World Seeds
	Yecora Rojo	CA AES & CIMMYT
1986	Butte 86	ND AES
	Cutless	ND AES
	Nordic	Nickerson American Plant Breeders
	Rambo	Western Plant Breeders
	Telemark	Nickerson American Plant Breeders
1987	PR2385	Pioneer
	Shield	SD AES
	Westbred 92	Western Plant Breeders

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CHAPTER 3

DURUM WHEAT

The Definition of Durum Wheat Quality

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Institutional Influences on Genetic Selection

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Grain Yield, Quality, Disease Interactions

CHAPTER 3

DURUM WHEAT

The Definition of Durum Wheat Quality

Durum (Triticum turgidum L. var. durum) is unique in that it is considered to have the hardest or most indurate endosperm of all commercial wheats. Durum wheat is most suitable as a raw material for use in products such as spaghetti, lasagne, elbow macaroni, etc., all of which are referred to generically as "pasta". A complete review of durum wheat and pasta quality can be found in two reports by Dick and Matsuo, in press, Dick and Youngs, 1988. Semolina (granular particle) or flour (fine particle) milled from durum, plus water are generally the two basic ingredients in pasta, thus pasta quality is the main criterion used to evaluate durum wheat quality. Although pasta is the primary product of durum, other products, e.g., couscous (gelatinized, dried particles of dough), bread, breakfast cereal (i.e., puffed wheat) and bulgur (gelatinized, dried wheat, usually cracked) are made from durum wheat either in the United States or in other countries.

The kernel of durum wheat is different from kernels of other classes of wheat in its shape, size, density, hardness and color. The durum kernel tends to be longer, larger, more dense and harder than kernels from other wheats. The embryo or germ tends to protrude more than the embryo of other classes. The bran of durum is amber (yellow-orange) in color whereas bran from other wheats usually is either red or white. Although durum wheat possessing red colored bran does exist, it is not grown extensively and is of little practical importance.

The physical characteristics of the durum wheat kernel are important especially as they influence market or end use quality. For example, greater kernel hardness is a desired attribute to the durum miller because it increases the yield potential of the most economically desired product, semolina. However, hard kernels can be a detriment to the farmer who when threshing the wheat must be careful not to crack or shatter the kernel so that the market value of the grain is not reduced and the "shrunken and broken" component of wheat grading increased. Size, shape and density of kernels also are important since they directly affect the milling potential of the grain. Uniformity in kernel size and shape allows the miller to adjust the mill for maximum semolina product yield. Kernels having relatively large size and high density contain a greater amount of extractable material because the innermost part of the kernel, the endosperm, is the structure converted to semolina and flour, the desired products of durum milling. While durum wheat is a specific class of wheat because of certain characteristics unique to it, variability within the class is apparent due to genetic differences and environmental conditions during growth of the durum wheat plant. For example, a given durum wheat variety might differ substantially from another variety in kernel size and density when grown at the same or variable locations, and, a variety usually will vary from year to year because of a response to variable environment during growth. While all varieties respond to growing conditions, some are much more variably responsive than others to the environment.

Durum wheat appearance and bran color are physical properties that have a significant influence on market value because durum wheat usually is not ground purposely into fine flour but is kept in the granular form, semolina. Durum wheat is milled to minimize the number of specks (small particles of bran, etc.) in the semolina. Removal of bran particles from semolina during the semolina purification process is important because specks not removed have a color which contrasts with that of semolina. However, amber color of durum bran is more desirable than red-colored bran, because of the similarity in color to the natural yellow of semolina. Defects or damage to the kernel which darken the amber-colored bran or make the bran more fragile and difficult to remove detract from the appearance of the semolina as well as from the finished pasta product. Abnormal bran color can be caused by the diseases blackpoint and scab or by the occurrence of rainfall and dew on the kernel surface during kernel maturation on the plant in the field which contribute to growth of bacteria and molds on the bran. In addition, wrinkled, flaked or broken bran caused by frost damage, broken germ (embryo) caused by sprouting, and cracked and broken kernels caused by mechanical damage due to handling the grain all can contribute to pasta of undesirable appearance.

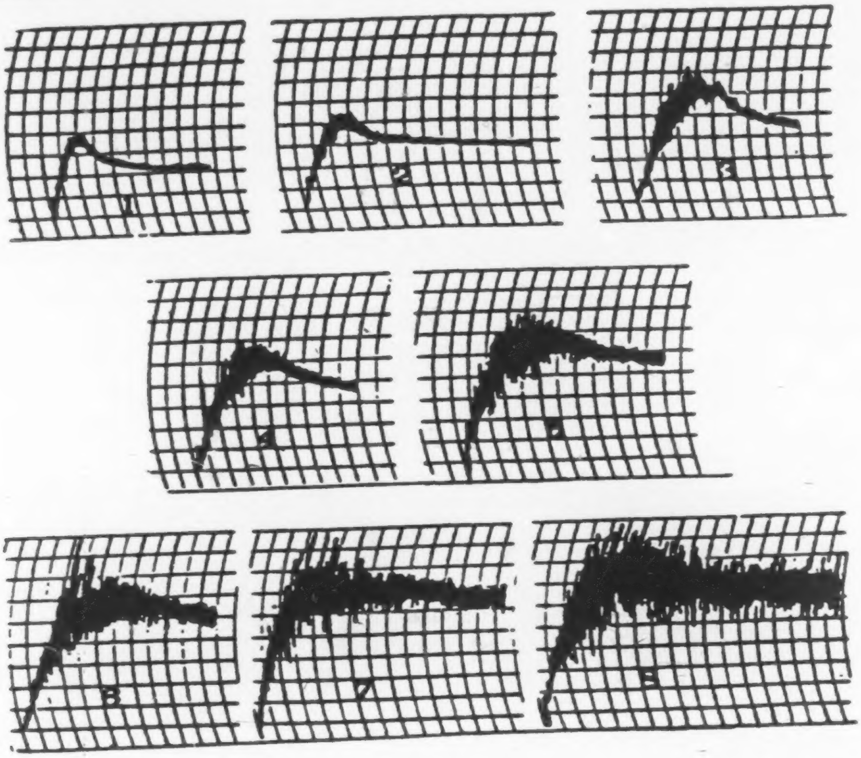
The physical nature of a lot or parcel of durum wheat may be described by the Official United States Standards of Grain of the Federal Grain Inspection Service (FGIS) which among other factors influences market value. The numerical grades [No. 1 to 5 or Sample grade (lowest grade)] are determined by the factors test weight (weight per unit volume), total defects (percentage of total damage, plus foreign material, plus shrunken and broken kernels), and percentage of contrasting classes (all other wheats which are not normally used to produce pasta) of wheat. In addition to numerical grade, a Subclass designation [Hard Amber Durum (HAD), Amber Durum (AD) or Durum (D)] is given to each sample graded. The subclass for durum is determined by the percentage of "hard and vitreous" kernels, vitreousness (glassiness) being judged by visual appearance of the whole, uncut kernel; hardness not actually being measured. Price discounts may be applied to Amber Durum and Durum depending on percentage of vitreous kernels and supply-demand relationship. Lots or parcels with the highest test weight and fewest general defects command the highest market price. Kernel hardness tests are available but none has yet been accepted in marketing channels to designate the subclass of durum.

Biochemically, durum wheat is similar to other wheats but differs in some characteristics. The grain of durum wheat is unique in that it possesses a naturally high level of yellow pigments called xanthophylls. These pigments impart a yellow color to the durum wheat endosperm, to the resulting milled products, semolina and flour, and ultimately to the finished product, pasta. Durum wheat, which was naturally more yellow than other wheats, incidentally gave the preferred firm and less sticky texture in the cooked pasta than other wheats and therefore was more acceptable. Pasta color is purely an esthetic consideration and has no measurable effect on nutritional or pasta cooking quality, although color historically has been associated as an indication of durum wheat quality.

All wheat is different from other cereal grains because its flour, when mixed with water, has the ability to form a strong, cohesive dough that will retain gas and produce baked products that are light and not dense. The gluten proteins are thought to be responsible for such properties. Gluten is the rubbery mass remaining after washing starch and water-soluble material from a flour-water dough. Durum wheat, which usually contains about 12 to 14% protein (14% moisture basis), is similar to hard red spring (HRS) wheat for protein percentage. However, the functional properties of durum protein are different than those of HRS and hard red winter (HRW) wheat proteins at the same protein percentage. Until the mid-1970's most durum wheat varieties grown in the United States had rather mellow and pliable gluten proteins which are referred to as "weak mixing", whereas since 1978 most new varietal releases contain a more elastic gluten of the "moderately-strong mixing" or "strong mixing" type (see Figure 3-1). The strong-mixing durums are more versatile functionally than weak-mixing types since they not only improve pasta cooking quality and textural properties of cooked pasta but, can be used to produce relatively good quality pan bread even though bread quality was not a primary consideration when strong-mixing types were developed. The weak-mixing types produce acceptable pasta but very poor quality pan bread. Protein quantity in durum is important because too little protein can reduce the mechanical strength of dry pasta, increase the loss of solids into the cooking water during pasta cooking, and reduce the firmness of cooked pasta. Protein functionality seems to be an overriding factor in determining pasta quality especially when protein percentage is low (Grzybowski and Donnelly, 1979).

The desirable pasta quality characteristics of yellow color, mechanical strength in the dry pasta, and firm (not soft or sticky, texture in the cooked product appear to be best fulfilled by durum wheat. While other wheats can and are sometimes used to make pasta, durum wheat is preferred. The desirable functional characteristics of durum wheat to produce other products such as couscous, bulgur, flat

Figure 3-1. Reference Mixograms for Durum Wheat Semolina Mixing Strength Classification; Higher Numbers Indicate Stronger Dough-Mixing Characteristics.



Source: Dick, J.W., D'Appolonia, B.L., Holm, Y.F., and Hansen, D. "Durum Wheat: 1987 Regional Quality Report," (Bismarck, ND, North Dakota State Wheat Commission).

bread and puffed wheat are less defined now than they are for pasta and pan bread.

Figure 3-2 shows a flow chart which summarizes how end-use quality of durum wheat is determined. Table 3-1 represents a typical computer printout which the cereal chemist would submit to the durum wheat breeder to assist in evaluating durum cultivars.

Objectives of Genetic Selection in Durum Wheat

Genetic improvement of durum wheat has been consistent since the establishment of the durum wheat breeding program in 1929 in North Dakota. The improvements have been in agronomic characters, disease resistance and grain quality. Improvement of grain quality characters has been a major objective in the development of new durum wheat cultivars. A review of selection in durum wheat for various quality traits is found in Cantrell (1987) and Joppa (1988). Durum varieties produced in the United States since 1978 are shown in Table 3-2. An example of agronomic data considered for release of a new durum cultivar is presented in Table 3-3.

In the early history of the breeding program, selection emphasized improvement in kernel size in durum wheat which led to improvements in milling properties. Selection also was conducted for a high level of vitreousness of the kernels which is positively related to milling performance and protein percentage. A high average test weight (grain weight/unit volume) was required of all durum cultivars developed and released. A genetic potential for satisfactory test weight was especially important in periods of disease epidemics, such as stem rust, which have the potential to dramatically reduce test weights. Because of unique characteristics of the durum kernel that easily

Figure 3-2. A Flow Chart Summarizing Procedures to Evaluate End Use Quality of Durum Wheat.

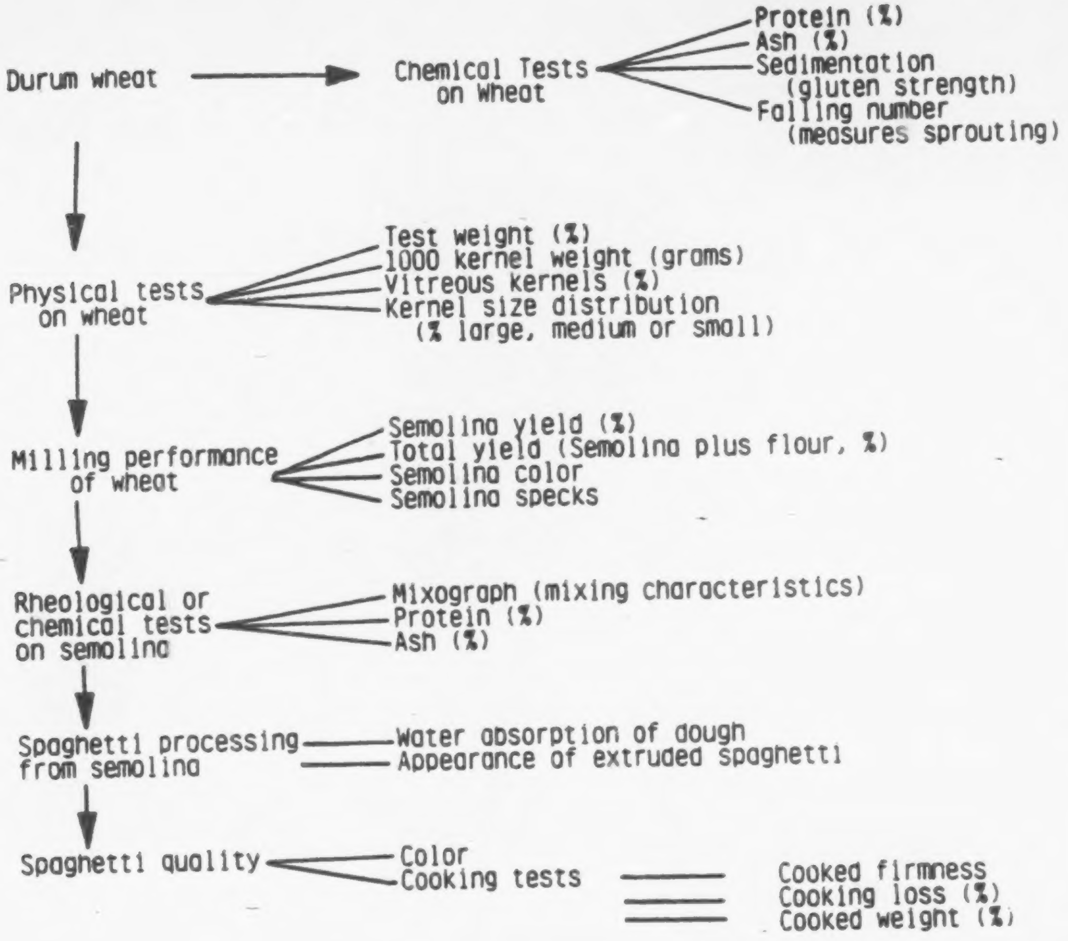

Durum wheat
Chemical Tests on Wheat
Protein (%)
Ash (%)
Sedimentation (gluten strength)
Falling number (measures sprouting)
Physical tests on wheat
Test weight (%)
1000 kernel weight (grams)
Vitreous kernels (%)
Kernel size distribution (% large, medium or small)
Milling performance of wheat
Semolina yield (%)
Total yield (Semolina plus flour, %)
Semolina color
Semolina specks
Rheological or chemical tests on semolina
Mixograph (mixing characteristics)
Protein (%)
Ash (%)
Spaghetti processing from semolina
Water absorption of dough
Appearance of extruded spaghetti
Spaghetti quality
Color
Cooking tests
Cooked firmness
Cooking loss (%)
Cooked weight (%)

Table 3-1. Quality Data on Durum Wheat Samples Grown in the Field at Fargo, ND, 1986 Crop.

VARIETY	STD	TEST WT	VK	1000 KWT	WHT PRO	SEMO PRO	TOT EXT	SEMO EXT	SEMO ASH	SPK	SPAG COL	MX	CKD WT	CKG LOSS	FIRM	% LG	% SM	SD	FAL NO	** VALU
WARD	S	52.8	70	23.8	15.7	14.4	64.8	57.2	0.89	93	9.0	3	30.4	7.1	5.9	4	23	29	234	1
VIC	S	54.7	82	30.3	15.7	14.4	65.5	56.4	0.80	73	9.0	5	30.6	6.8	6.4	10	10	43	350	4
LLOYD	S	48.0	56	25.5	15.7	14.6	63.2	54.8	0.88	120	8.5	4	30.0	8.2	6.8	6	22	49	75	1
MONROE	S	55.6	74	33.8	14.9	14.0	66.3	57.4	0.78	87	9.0	7	30.1	7.2	6.4	29	5	46	343	4
D8172		54.3	59	27.2	15.4	14.3	66.4	58.4	0.80	97	9.0	6	30.1	7.9	6.0	6	19	36	279	3
RUGBY		54.6	64	24.9	15.5	14.6	65.0	56.6	0.83	107	9.0	3	30.8	7.4	5.6	7	18	26	251	4
MEDORA		56.7	76	31.4	15.6	14.1	65.5	56.3	0.75	110	9.0	6	30.1	6.6	5.9	15	6	48	328	4
ARCOLA		51.2	44	27.5	15.6	14.7	65.3	56.5	0.85	103	8.5	5	31.1	8.1	6.0	10	11	48	265	3
KYLE		50.1	57	27.2	16.1	15.0	63.9	56.2	0.91	143	8.0	4	29.6	7.3	7.1	7	15	42	143	1
LAKER		48.1	51	20.4	14.1	14.8	63.3	55.2	0.94	130	8.0	7	30.1	7.6	7.1	7	21	55	220	1
D79160		52.8	50	28.2	14.9	14.8	65.6	56.9	0.82	100	8.5	5	29.5	7.4	6.7	5	25	43	179	2
D79209		53.3	53	26.8	14.4	13.0	64.9	56.9	0.80	107	9.0	5	30.3	7.3	6.1	7	14	42	240	2
D8012		54.7	55	26.1	15.6	14.4	66.6	57.6	0.85	103	9.0	6	30.3	7.5	6.7	20	8	42	273	3
D8016		55.7	50	30.7	15.5	14.4	67.2	58.2	0.80	113	9.0	5	29.9	7.3	7.1	16	8	37	298	3
D8019		53.1	54	32.4	15.2	14.0	65.4	56.8	0.79	107	9.0	7	30.5	7.0	6.3	24	5	38	313	3
HAND81-444		54.3	43	28.2	15.0	13.7	65.8	57.3	0.89	137	8.0	6	29.7	7.6	6.3	6	14	43	237	1
HAND81-485		56.7	61	29.9	15.1	13.9	65.8	57.0	0.81	90	8.5	8	29.7	7.4	6.4	14	10	46	296	4
D8191		52.5	45	30.6	14.8	13.3	66.8	58.5	0.84	127	8.0	6	30.2	7.0	6.0	22	6	40	235	1
D8193		54.2	58	29.9	15.6	14.2	66.7	58.3	0.85	103	8.5	5	29.8	7.0	6.8	13	10	47	236	3
D8194		55.7	48	25.1	14.6	13.4	65.2	56.9	0.82	113	9.0	5	30.2	6.8	6.5	17	7	44	247	3
D81151		51.2	41	27.2	14.9	13.8	65.3	57.2	0.84	103	9.0	3	30.9	7.5	6.1	19	10	32	104	3
D81154		55.0	52	27.0	15.6	14.4	63.7	55.4	0.82	107	9.5	5	29.9	6.8	7.3	10	14	37	277	3
D81183		51.5	31	25.6	14.6	13.6	63.9	55.6	0.84	103	8.5	4	30.2	6.8	6.6	11	16	47	124	3
D8261		52.1	37	27.0	15.3	14.5	65.3	56.5	0.92	137	8.5	4	29.5	7.0	7.0	8	21	42	182	1
D8263		53.1	37	26.3	14.8	14.0	63.0	53.9	0.85	117	9.5	5	29.8	6.4	7.5	6	16	47	243	1
D8269		53.6	42	28.3	14.7	13.6	65.4	56.5	0.82	113	9.0	4	30.2	6.6	6.6	9	15	44	177	3
D8279		54.4	46	29.6	14.6	13.3	65.3	56.5	0.81	130	9.0	4	30.2	7.5	6.1	12	11	43	225	2
D8291		53.1	46	28.4	14.4	13.7	65.1	55.5	0.84	120	9.0	4	30.2	6.9	6.9	7	18	46	255	3
D82136		55.3	53	26.7	14.8	13.5	64.2	55.9	0.80	123	8.5	5	30.2	7.7	5.9	7	13	40	253	3
FA883-323		56.0	60	28.8	14.8	13.4	66.4	57.1	0.80	97	9.0	5	29.7	7.4	6.4	17	9	40	257	4

DEFICIENCIES	TW	VK	KW	SA	SP	TX	SX	SK	MC	FR	LG	SM
AVG OF STANDARDS	52.8	71	28.1	0.84	14.3	64.9	56.4	93	8.9	6.4	12	15
MINOR FAULTING VALUES	50.6	66	26.0	0.87	13.3	62.9	54.4	112	8.4	5.4	5	10
MAJOR FAULTING VALUES	49.7	61	23.0	0.89	12.8	61.9	53.4	131	7.9	4.4	1	21

** EVALUATION 1=NO PROMISE, 2=LITTLE PROMISE, 3=SOME PROMISE, 4=GOOD PROMISE

STD = Standard varieties; TEST WT = Test weight, pounds per bushel; VK = Vitreous kernels, %; 1000 KWT = one thousand kernel weight, grams; WHT PRO = Wheat protein, %; SEMO PRO = Semolina protein, %; TOT EXT = Total (Semolina plus flour) extraction, %; SEMO EXT = Semolina extraction, %; SEMO ASH = Semoline ash, %; SPK = Semolina specks, number per ten square inches; SPAG COL = Spaghetti color, units; MX = Mixogram score (see Figure 3-1); CKD WT = Cooked spaghetti weight, grams; CKG LOSS = Cooking loss, grams; FIRM = Cooked spaghetti firmness, grams - centimeters; LG = Large kernels, %; SM = Small kernels, %; SD = Microsedimentation, millimeters; FAL NO = Falling number, seconds, VALU = Evaluation.

Source: Computer printout of 1986 field plot durum wheat samples grown at Fargo, ND, as prepared by Joel Dick, Associate Professor, Cereal Science ad Food Technology Department, NDSU, Fargo, ND.

Table 3-2. Durum Wheat Cultivars Grown in the United Stated During the Period 1978-1987.

Year released	Cultivar name	Origin
1979	Vic	NDSU-USDA
1972	Ward	"
1973	Rugby	"
1973	Crosby	"
1975	Cando	"
1971	Rolette	"
1983	Lloyd	"
1978	Calvin	"
1973	Botno	"
1978	Edmore	"
1960	Wells	"
1966	Leeds	"
1955	Langdon	"
1960	Lakota	"
1985	Monroe	"
1975	Mexicali	CIMMYT-Mexico
1979	Yavoros 79	"
1971	Cocorit	"
1974	Crane	"
1969	Jori 69	"
1979	Aldura	Northrup King
1974	Produra	"
1972	Wakooma	Canada
1978	Coulter	"
1979	Macoun	"
1966	Hercules	"
1985	Sceptre	"
1982	Medora	"
1976	Modoc	California
1986	Fjord	NAPB-Agripro
1986	Stockholm	"
1982	Westbred 881	Western Plant Breeders
1979	Westbred 1000-D	"
1985	Laker	"
1986	Turbo	"
1982	Westbred 803	"
1980	Waid	Washington
1981	Wandell	"

Table 3-3. Performance of Monroe and Check Cultivars in North Dakota, Minnesota, Montana, South Dakota, Manitoba, and Saskatchewan in 1981-1984.

Trait	Station years	Monroe	Vic	Ward	Rolette
AGRONOMIC:					
Yield, bu/a	47	46.8	46.7	46.1	44.4
Test weight, lb/bu	39	59.4	60.2	59.9	60.5
Kernel weight, mg	20	43.0	41.2	37.8	39.0
Days to head	35	59.7	62.0	61.7	59.3
Height, cm	40	87.9	92.9	92.4	89.6
Lodging, 0-9	14	3.3	2.9	2.8	3.8

distinguish it from other classes of wheat, little attention has been paid to kernel morphology.

Semolina color was a very important quality trait to achieve early in the durum wheat breeding project. The yellow color is a result of xanthophyll pigments present in the endosperm of durum wheat. The amount of the pigment was increased plus the activity of enzymes, such as lipoxygenases, which degrade the color in the pasta, were reduced. A high level of lipoxygenases can breakdown the yellow pigment and result in white or grayish-colored pasta products (Irvine and Anderson, 1953).

Small black or brown specks in the semolina are very undesirable because they result in specks in the pasta. Disease affecting the bran of the durum wheat kernel can contribute to a high level of specks in the semolina. Black point or kernel smudge is a complex fungal disease that often develops on the durum wheat kernel. No absolute genetic resistance to this disease complex is available but selection for disease tolerance within durum wheat progenies has reduced its severity.

Various biochemical characteristics of the durum wheat kernel have a major influence on grain quality. Protein quantity and protein quality influence the processing and end-product quality of durum wheat. The major genetic improvements have been achieved in protein quality. In the early 1970's a concentrated breeding effort was initiated to improve the gluten strength of durum wheat in North Dakota. The strength of the gluten is determined by the gluten quality and is related to cooked spaghetti firmness (Matsuo and Irvine, 1970). Improvements were made in gluten quality in the breeding program by utilizing such predictive tests as the mixograph and the sedimentation test (Dick and Quick, 1983).

A range in protein percentage of durum wheat from 12 to 14% is common in North Dakota. A long-term average would be approximately 13.5 percent. Selection for high protein in durum wheat has been limited compared to that in hard red spring wheat where it is a major quality and marketing factor. In recent years, a greater emphasis has been placed on selection for high protein percentage in durum wheat in response to perceived requirements of the domestic pasta industry. High protein genes are being introduced from durum wheats from Sicily and Israel in an attempt to breed higher protein durum cultivars for North Dakota.

The quality of the raw material (durum wheat) ultimately relates to end use functional quality. In the United States, pasta is the primary end-product for durum wheat. The ultimate pasta product is bright yellow in color, firm after cooking, not sticky, and tolerant to overcooking. Bright yellow semolina that is free from dark specks is commonly produced from durum cultivars in North Dakota as a result of major breeding achievements for many years. Several new, strong gluten cultivars have been developed since 1978 and these have very desirable cooking characteristics, such as firmness and tolerance to overcooking. Further improvements in protein percentage and gluten quality are anticipated.

Institutional Influences on Genetic Selection

Administrators of the North Dakota Agricultural Experiment Station interpret research needs and allocate funds from state and federal sources. Appropriated support from the North Dakota

Legislature for durum wheat improvement began in 1971 and continues to this date. The funds are directed to the most vital research needs in the durum improvement program providing resources for research in breeding and genetics, pest control especially plant diseases, evaluation of end-use qualities, and product marketing. This appropriation supports research that has a direct effect on the North Dakota farmer and all other citizens who support the program via tax dollars. The influence from this area often is directed towards maximizing economic return from growing durum wheat. Also, countering hazards such as disease epidemics are frequently mentioned.

The North Dakota Wheat Commission has provided grant funds for durum breeding since 1978. They influence genetic research on quality traits of interest to domestic and export markets. The United States Durum Growers Association does not directly fund research but does have representatives on the Wheat Commission that communicate the interests of the durum grower.

The National Pasta Association primarily represents the miller and the pasta manufacturer and has supplied grant funds for quality-oriented research on durum wheat since 1978. The influence of the domestic pasta industry is important in formulating breeding objectives that produce a superior raw material for pasta production.

A minor influence on the direction of the durum wheat breeding program would be from trade teams from international customers that visit the Northern Crops Institute at North Dakota State University. The agenda for many of these teams is arranged by United States Wheat Associates. They communicate to us the concerns of the export market. Almost all of the issues raised are in relation to grain quality, such a gluten quality, sprouting, protein percentage, and yellow color, however, price of the durum wheat also has a strong influence on trade. For example, trade teams from Italy influenced the United States shift to strong gluten durum wheat in the late 1970s. An additional influence was competition on the export market from Canada and Argentina, who produced durum wheat with strong gluten.

The North Dakota Agricultural Association and North Dakota Crop Improvement Association influence the breeding program mainly via their participation in commodity organizations. They often solicit information regarding durum wheat cultivars that can be distributed to their membership.

Future Objectives for New Markets or Non-traditional uses

The United States is one of the major exporters of durum wheat and always must be cognizant of the quality requirements of the domestic as well as the export market. Although durum only composes about 5% of all wheat production in the United States and the world, demand for it among traditional users appears to be increasing. Some recent users, such as Japan, and non-traditional users, such as Korea are potential markets for increased use of durum in pasta. Algeria, a large user of durum wheat for couscous and flatbread, appears to be increasing its requirements for use in pasta. Italy, the largest per capita consumer of pasta, exports pasta worldwide and now makes substantial amounts of bread from durum. Italian exports to many South East Asian countries have enabled their people to try pasta as a food product. Several Central and South American countries realize the potential for improving pasta quality using durum wheat, though increased utilization of durum wheat is inhibited by the high price of durum wheat compared to other wheats. The potential for increased demand for durum wheat in the export market appears to depend on increased per capita consumption of high quality pasta and use of more durum wheat in bread. Changes in use of durum wheat in products other than pasta or bread will very likely follow population trends only. The nutritional attributes of pasta as a product high in complex carbohydrates and low in fat have increased the awareness to consumers that pasta is not a fattening food, as once perceived. All of these facts point to an increased world demand for products made from durum wheat even though durum wheat is relatively more expensive than other wheats. The United States annually exports at least 50% of its durum so it is important that plant breeders and cereal chemists responsible for developing new varieties be cognizant of the quality requirements of all consumers, including those that use durum for products other than pasta, especially bread and couscous.

Genetic Influence on Durum Wheat Quality

The genetic control of a specific character often is defined in terms of heritability and the number of genes controlling expression of the character. A highly heritable character may be controlled by one or a few genes and is influenced little by environment in which the crop grows. Whereas, a character with low heritability may be controlled by many genes and variability in the character often is due to the environment.

The physical quality of the grain, such as, test weight and kernel weight probably has the lowest heritability of any of the grain quality characters. Improvement of test weight and/or kernel weight from genetic selection is possible for these traits but much of the variation results from the environment in which the crop grows. Most of the durum wheat is grown in North Dakota in areas where environmental stress can occur but is infrequent.

Gluten strength is a major quality character that is highly heritable and controlled by relatively few genes (McClung and Cantrell, 1986) permitting early generation selection and rapid progress for this trait.

Semolina color also is controlled by a few genes and is highly heritable (Johnston et al., 1983). Enhanced yellow color is achieved easily in a breeding program by careful selection of parental material and early generation selection. A high level of yellow color has been incorporated into all North Dakota durum wheat cultivars.

Protein percentage has moderate to low heritability, therefore selection for this character is difficult because of the strong environmental influence, and it must be evaluated in many environments or locations.

Pasta quality is the end result of the expression of many genetic characters which is difficult to quantify. Many of these characters are very complex and interact with each other.

Grain Yield, Quality, Disease Interactions

Durum wheat breeding often involves balancing the level and expression of many agronomic, disease and quality characters to develop improved cultivars. Many of these characters are not independent of one another if the genes are located in close proximity on the same chromosome and inherited together, i.e., as a linked group. A single gene also may influence more than one character. These character associations and interactions complicate the breeding process.

An inverse relationship between grain yield and protein percentage is a common phenomenon in durum wheat. This condition is observed on a statewide basis when favorable growing conditions occur to produce above average grain yields per acre along with below average protein percentage of the grain. Grain protein percentages can fluctuate up to 2 percentage points from year to year even though the cultivars grown may not change significantly.

When breeding for higher grain yield, a protein percentage of 13.5 is difficult to maintain. A genetic association of lower protein with the reduced straw height (semidwarf) gene that is frequently used in breeding programs has been reported (McClung et al., 1986). The semidwarfs average one percentage point lower in protein than their taller counterparts when grown in the same environment. The unfavorable genetic association does not mean that high yielding short cultivars with acceptable protein percentage cannot be developed but that the breeding process is lengthy, more difficult and complex.

Although durum wheat cultivars now grown for commercial production have excellent quality, intensive selection for many quality traits must continue in the breeding program. Different durum wheats from all over the world, as well as wild relatives of wheat, are continually being crossed to introduce new genes, e.g., for disease resistance. This germplasm, containing the new gene, may have resistance to disease but produces poor quality pasta thus intensive breeding is required to transfer the desirable genes for disease resistance into durum wheat that will produce good quality pasta.

Disease infection can have a dramatic influence on grain quality characters. Stem rust is a disease that reduces grain yield but also lowers test weight and kernel size (Roelfs, 1986). Genetic resistance to this disease stabilizes production and quality. Joppa (in press) describes how new stem rust resistant cultivars were developed to overcome the wheat stem rust epidemics of the 1930s and the 1950s. The fungus that incites wheat stem rust is capable of producing new rust races that overcome resistance genes in some durum wheat cultivars thus breeding for resistance is a continuous process.

Durum wheat is a polyploid with 28 chromosomes and its evolution is very complex. Several wild grass species were involved over thousands of years to evolve into durum wheat as we know it today. Evolution has maintained significant genetic variation in the species. Genetic variation must be present for plant breeding to be successful. Genetic variation must be maintained especially in durum wheat breeding because only one public plant breeding program in the United States develops new durum cultivars. The one public program is in North Dakota and the durum wheat breeder and cooperating ARS-USDA geneticist search for valuable genetic variation in the USDA World Wheat collection that contains wheat collected from around the world. This effort is difficult because of the limited amount of data available to adequately describe entries in the collection. The amount of quality data is extremely lacking. This collection provides a gene reservoir for plant breeding in the future. Many disease resistance genes have been found in this wheat collection but unfortunately resistance to a few important diseases, such as Scab and Septoria Glume Blotch has not been found making the task of breeding for resistance to these diseases almost impossible.

As mentioned earlier, quality for pasta production is a major breeding objective in durum wheat. The emphasis placed on quality has led to a very narrow genetic base in durum wheat. A few high quality parents have been used repeatedly as parents in the breeding program. As a result, the cultivars grown are all very closely related. Over 90% of the entire durum acreage in the United States is grown to cultivars developed by the Agricultural Experiment Station, North Dakota State University.

About 85% of the durum wheat production in the United States is grown in North Dakota. A year with poor growing conditions easily can influence this entire region and severely damage the quality and quantity of the total United States durum wheat production. Annual variations in the quality of the durum crop occurs more often than for any other wheat class because of the restricted production area.

Sprout damage is one of the more serious quality problems encountered if significant rainfall is received in North Dakota during harvest (Dick et al., 1974). Research is in progress to develop durum cultivars that have genetic dormancy factors to reduce the damage from pre-harvest sprouting (Soper et al., 1987).

Uncontrolled environmental conditions such as frequent rainfall and high humidities during critical growth stages of the plant favor the development of several important diseases. Prolonged wet periods favor development of tanspot which can be a serious leaf spotting disease of durum wheat (Hosford, 1982). If wet conditions persist during the flowering period and temperatures are above average, then scab can be a serious problem in durum wheat. Scab can severely reduce the test weight. Disease incidence and quality damage often is very sporadic depending on the timing of the wet periods in relation to the growth and development of the crop.

In addition to the uncontrolled environment, the management practices of the farmer represent a "controlled" environment to a certain degree. Several of these management practices may impact the quality of the durum wheat crop. For example, a significant portion of the durum wheat acreage is harvested by first swathing (cutting the straw and placing in windrows) and then combining after 2 or 3 days of drying. The ripe durum wheat in the swath or windrow is very susceptible to sprout damage if rains occur. Direct combining without swathing reduces the risk of sprout damage but artificial grain drying usually is required.

Nitrogen fertilization is a critical management practice. Inadequate soil nitrogen may reduce grain yield and grain protein percentage. This reduction in grain protein is usually greater if semidwarf durum cultivars are being grown.

The effect of minimum or reduced tillage on disease development in wheat is discussed by Hosford (1982). The extra stubble remaining on top of the soil on the fields provides an ideal site for many plant pathogens to overwinter. A large supply of disease inoculum for diseases such as tanspot, Septoria glume blotch and Septoria leaf spot then is available for infection in the spring of the following year. All of these diseases reduce grain yield and test weight if serious epidemics occur.

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CHAPTER 4

SOFT RED WINTER AND WHITE WHEAT

Introduction

Soft wheat breeders of the eastern United States began to develop soft red winter (SRW) and soft white winter (SWW) wheat with specific improved quality attributes after the establishment of the USDA Soft Wheat Quality Laboratory (SWQL) in 1937. Since establishment of the SWQL, continued refinement to define and measure wheat and flour milling and end use quality parameters has occurred along with closer adherence to those parameters in varieties* developed by public breeders.

The Definition of Wheat Quality

The quality of any kind of wheat cannot be expressed in terms of a single property, but depends on several milling, chemical, baking, processing, and physical dough characteristics, each important in the production of the many wheat-based foods. "Superior quality" soft wheats are those which conform to the milling and food processing performance of widely grown commercial varieties. Good milling soft wheats are those which fracture into flour particles with significantly smaller mean volume diameters than hard wheats, the endosperm is comparatively easily separated from the bran, the endosperm particles are easily reduced into flour, and the flour has good bolting or sieving properties. Simply stated, a superior milling soft wheat produces a high percentage of fine flour with minimum milling energy input. Historically, and in general, superior soft wheat flours have low water absorptions, low to medium-low protein percentages, high break flour yields (the flour that is produced by the corrugated rolls in a roller mill that break the wheat apart), and produce large diameter cookies and large volume cakes.

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*Cultivar = variety = cultivar throughout

Physical Quality Characteristics

The kernel of soft wheat must be comparatively easily crushed as milled and produce relatively high break flour yields having comparatively small flour particle size.

Club wheats are distinguished from common soft wheats by shorter, laterally compressed spikes. Consequently, the kernels are small and laterally compressed and have a "pinched" asymmetrical appearance. Most club wheats have a narrow, very shallow crease.

Biochemical Quality Characteristics

Soft red winter wheat flour is preferred for many products in three broad groups: (1) chemically leavened products such as cookies, crackers, cakes, pie crusts, biscuits, donuts, and wafers; (2) yeast leavened products such as saltine crackers, many international flat breads, pretzels, and some French-type breads; and (3) non-baked products such as noodles, batters, breadings, and gravies.

Relatively little is known which relates specific biochemical constituents to soft wheat end product quality except:

1. Low damage starch is desired because it is associated with stickiness in production.
2. Low (9 to 11%) protein percentage is desired for cookies and cakes, since higher protein is associated with coarser textured products.
3. Higher protein percentage is desired for flat breads, crackers, and pie crusts to add structure to these products.

4. Fine flour particle size is desired for all products because it is generally perceived to impart soft texture to end products.

Minor biochemical components of Eastern soft red winter wheat include the pentosans, lipids (fats or fatty acids), enzymes (in fermented products), and their interactions.

Physical Quality Characteristics

In general, the important biochemical components of soft white wheats are the same as for the soft red wheats except that the lighter bran from white wheats is used in breakfast cereals as a fiber source. However, it is noteworthy that Eastern (Michigan and New York) soft white cultivars generally produce larger cookies, have finer flour particle size, are less coarse milling wheats, and hydrate less water than soft whites from the Pacific Northwest. The club cultivars from the Pacific Northwest are distinguished by producing extremely soft textured products, especially cakes. Club wheats have the highest flour yields of all U.S. cultivars, irrespective of class, despite their small asymmetrical kernel. The biochemical bases for the differences in the perceived milling and baking qualities of the various soft red, white and white club wheats are not understood. As described earlier, the kernel morphology of club wheats is distinct from the other soft red and white wheats.

Functional Quality Characteristics

Soft wheat functional (end product) quality is far more complex to define than milling quality, primarily because soft wheats are the preferred flour source for a multiplicity of products. The diversity of end uses and lack of definitive information on the physics and chemistry of soft wheat flour and its products greatly complicate defining end product quality. The soft wheat flour quality requirements for many cookies, cakes, crackers, and breads vary so that rarely does a cultivar possess all the ideal attributes for each product. However, in general, functionally superior soft wheat flours have low water absorptions, low to medium-low protein percentages (in the 9 to 11% range), high break flour yields which are comparatively soft rather than coarse textured, and produce large diameter cookies and large volume cakes.

Objectives of Genetic Selection

Major Quality Characters Which Breeders Have Stressed Over Years

The objectives of genetic selection are to produce new cultivars with milling, baking, and other end use quality equal-to or better-than, but resembling today's cultivars so that they should not be disruptive when introduced into the market, thereby maintaining or improving the end product quality of today's soft wheat cultivars. While many soft wheat kernel quality characters have been defined and are continually improved in most new cultivars developed over the past 40 to 50 years, most millers or bakers would consider these improvements as micro-changes rather than macro-changes in that the milling and baking characteristics of soft wheat cultivars of 40 to 50 years ago were very similar to those of today's cultivars.

Physical characters related to grain quality which are routinely used by soft wheat breeders as selection criteria include plumpness, size, uniformity, and appearance of kernels, and test weight. These characters are considered important as they relate directly or indirectly to milled flour yield and characteristics, and to end use quality. Biochemical characteristics such as protein percentage, alkaline water retention capacity (AWRC), flour ash and flour particle size also are used as progeny selection criteria in breeding soft wheats. Although a wide array of end products are produced from soft wheats, certain predictive tests, primarily a standard formula cookie and cake test, are used as the primary selection criteria in breeding programs. Most soft wheat products (e.g., cookies, cakes, pie crusts, biscuits, donuts, pancakes, cones) require low water absorption, fine particle size, and weak gluten. Flours for fermented crackers require stronger gluten. Low starch damage during milling is desirable. Generally very low (or no) amylase in the kernel or flour from soft wheat is preferred. If the flour from soft wheat does not meet needed specifications for an end product, additives, shortenings, flour treatments and many other ingredients can be added to approximate the desired end product to greater or lesser degrees.

Soft wheat breeders use end use quality data such as a final milling, baking, and combined score to evaluate progeny performance regarding discard as well as other qualitative information as described earlier in this section (Table 4-1) for further release. This information usually is evaluated subjectively (differently perhaps by each breeder) along with yield and other agronomic data, and reaction to diseases and insect pests to decide on release/discard of each experimental line after several years of testing.

Institutional Influence on Genetic Selection

A great diversity appears to prevail among regions of the United States regarding institutional influences on breeding wheat for end use products in the United States or for export. In contrast to the many institutional influences listed for hard red spring and durum

Table 4-1. Milling and Flour Analytical and Baking Data, and Soft Wheat Quality Scores for 1986 Advanced Nursery Entries from Wooster, Ohio.

Lab No.	Entry	Milling Quality Score[2]	Baking Quality Score[2]	Comb. Quality Score[2]	Micro Test Wt kg/hl	Softness Equiv. %	Flour Yield %	Flour Ash %	Flour Protein %	Micro AWRC %[3]	Cookie Diameter cm[4]	Top Grain[5]
	Standard[1]	100 A	100 A	100 A	72.2	62.2	71.1	.35	8.9	55.3	18	5
	Benchmark	105.5 A	107.4 A	105.5 A	78.6	61.4	73.6	.35	7.9	52.9	18.2	7
607	OH 371	101.7 A	76.7 F	76.7 F	75.8	62.3	71	.33	10.4*[6]	58.7*	17.5*	7
608	OH 343	98.3 B	99.4 B	98.3 B	73.2	60.8	70.5	.32	9.8*	54.5	18.0	7
609	Caldwell	105.2 A	103.3 A	103.3 A	76.2	65.5	71.4	.31	9.5	55.7	18.2	6
610	OH 288	93.2 C	77.3 F	77.3 F	75.4	57 *	69.9*	.35	10.5*	56.6	17.4*	6
611	OH 362	93.2 C	90.8 C	90.8 C	72.7	63.4	69 *	.34	10 *	55	17.6*	6
612	OH 331	98.4 B	82.7 E	82.7 E	76.3	56.8*	71	.33	10.2*	53.8	17.4*	6
613	Titan	96.4 B	90.9 C	90.9 C	73.6	60.6	70 *	.33	9.2	56.5	17.8	6
614	Becker	100 A	100 A	100 A	72.2	62.2	71.1	.35	8.9	55.3	18	5

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[1] Standard = 86614, Becker.

[2] Quality number classification: A = 100 and greater, B = 95 to 99.9, C = 90 to 94.9, D = 85 to 89.9, E = 80 to 84.9, F = 79.9 and lower.

[3] Alkaline water retention capacity test using 1 g flour.

[4] Diameter based on 2 cookies.

[5] Cookie top grain based on subjective evaluation from 1-9, 9 being outstanding.

[6] Values that deviate (in the wrong direction) from the standard by one $LSD_{0.05}$ are designated with one asterisk (*).

wheat, the SRW wheat region has no Wheat Commissions, Quality Advisory Councils, Growers Associations, Crops Institutes, Agricultural Associations, and only 2 states (North Carolina and Arkansas) belong to the National Association of Wheat Growers. The USDA Soft Wheat Quality Laboratory, Wooster, Ohio, serves as the primary watchdog for all end use quality considerations. A minor influence is the direct contact with individual millers and/or bakers primarily at the Annual Soft Wheat Quality Research Review Conference in Wooster, Ohio. SRW wheat breeders, using data on wheat progeny evaluations from the Soft Wheat Quality Laboratory, have traditionally made independent decisions whether to retain or discard potential new cultivars based on end use quality characteristics.

Future Uses of U.S. Soft Wheat (New or Old Markets).

Perhaps the U.S. population is both its own best customer, as well as its most likely source for "new markets". Today much is known about the health benefits of diets high in bread and other wheat-based foods. Getting "the story" to the public thus greatly increasing domestic consumption of wheat-based foods is likely necessary if wheat surpluses are to be reduced thereby helping to keep U.S. wheat farmers solvent.

Genetic Influences on Wheat Quality

Quality Characters Under Genetic Control

Control of most quality characters in soft wheats is either multigenic or the inheritance of the trait is unknown. Inheritance studies of quality traits is, at best, difficult due to (1) great environmental influence on quality parameters, (2) the lack of understanding of the influence of specific physical and biochemical parameters on end product quality, and (3) the difficulty in obtaining definitive quality parameter measurements on a per plant basis which are essential to study the number of genes and loci involved.

Physical Quality. Characters reported to be controlled by only a few genes include kernel color (Ausemus, McNeal, and Schmidt, 1967), kernel texture (Aamodt and Torrie, 1935), and kernel weight (Sharma and Knott, 1964). All other kernel traits appear to be multigenic and/or multiallelic, i.e., have complex inheritance. Also, modifying genes have been reported for almost all traits including those above.

Biochemical Quality and Functional End Use Properties. Inheritance of biochemical characteristics and functional end use properties have not been studied in the soft wheats, but would likely be controlled by many genes with complex inheritance complicated by interaction with the environment. The reader is referred to the sections on hard red spring and durum wheat for additional information.

Interaction of the Characters: Grain Yield, Disease Reaction, and Grain Quality

Many interactions are known and others are suspected to exist among these traits. Many negative relationships exist between yield and quality due to the multigenic control of both traits, except as described below for grain yield and grain protein. The bringing together of desirable combinations of high yield and favorable quality genes are the exception rather than the rule when breeders attempt to combine parents to produce new breeding populations, especially when unadapted types, other market classes, and exotic germplasms are used as parents. In soft wheats, one important physiological association, the negative correlation of yield and protein at high yield levels (Olson, Frank, Deibert, et al., 1976) is extremely beneficial as it allows concurrent progress in these traits (high nitrogen fertility necessary for high yields does not necessarily result in undesirably high protein flour).

Although genetic associations of desirable disease and insect resistance traits with undesirable quality traits frequently occur, the gain in quality improvement due to increases in kernel size and plumpness resulting from incorporation of resistance to many diseases and insects offsets these associations. In general, reductions of plant stresses result in improved quality characteristics of the kernels produced.

Genotypic Variability. While genus and species limitations (biological constraints) do establish end points to the range of genetic variation for all quality parameters, considerable variation does exist in wheat germplasm available to breeders. Unfortunately, the current level of optimization or improvement is approaching the maximum attainable levels of known class variation for the important soft wheat quality parameters such as percent flour yield, particle size, AWRC, percent ash, and, percent break flour yield. Also, an important consideration is that in an overall plan of research, soft wheat breeders do not normally attempt attainment of new, higher, specific quality goals, but rather attempt to generate experimental populations with improved agronomic characteristics and either (1) acceptable quality, (2) quality consistent with cultivars in production, or (3) slightly improved overall quality. Production priorities and market place incentives do not offer any reward for greatly improved quality traits, thus breeding priority is given to other traits such as improved yield, straw strength, disease resistance, etc.

Genetic vs Environmental Interactions. Soft wheats and other classes appear to be most adapted and are produced in well defined climatic zones (Huffman and Evenson, 1987). Rigorous genetic selection and adaptive breeding probably could expand the production zones of some or all classes. However, if major changes in market class production zones occurred, wheat grain from the zone margins might not fit the "typical" for the class and more class admixtures could occur in marketing. The utilization of specific zones for production of specific market classes has evolved to its present status since emigrants first brought wheat to the United States, and has a very valid biological basis. Environmental variation occurs within climatic zones and varies with years and locations, however, the ranges in variation are not considered as great as between regions. Genetic by environment interactions abound and influence all soft wheat quality parameters. Fortunately, variations in quality caused by these interactions are usually within acceptable limits.

Storage and Handling of Wheat Classes. (Written by J.F. Carter to apply to all classes)

The grain of wheat can be stored safely in good condition if acceptable procedures for sanitation, control of insects, starting storage at a safe grain moisture content, and cooling to below 45° F. are achieved or ensured. Cooling grain in storage to or below 45°F may not be possible in some areas, e.g., the Southeast, but other requirements for safe storage can be achieved. In general, wheat grain can be stored longer and kept in good condition in northern areas having colder temperatures but all other requirements for safe storage must be met in the north after air temperatures rise in the spring. In general, wheat in the southern production areas of the soft red winter and hard red winter wheat classes are stored a shorter time in on-farm storage and tend to be delivered to country elevators at harvest or before farm storage is needed for soybeans and corn later. Conditions related to farm storage and handling in the marketing process are not considered of great significance by wheat breeders as they consider breeding for grain quality. Wheat breeders are not evaluating or attempting to change wheat of any class for increased resistance to damage from storage insects because (1) insect damage is related closely to storage sanitation, (2) the bran or pericarp of all known germplasm is penetrated by insects quite easily, and (3) the introduction of a natural protective chemical into the wheat kernel risks great problems with clearance from Food and Drug Administration even though the protective component may be "generally recognized as safe" for people.

Breeding for Specific Markets

Both Eastern and Western soft wheats of the United States are generally bred for the same diverse uses discussed above, with the notable exception that Eastern wheat breeders do not consider the Pacific Rim needs (e.g., Japanese sponge cakes, Japanese noodles, Chinese steam breads) as do the Western soft white wheat breeders.

Variety Release

Number of Varieties

Soft Red Winter Wheat. Approximately 85 SRWW cultivars have been released in the Eastern U.S. since 1977 as well as 10 hybrids. Of these 85 cultivars, 37 have been released by private companies while 48 have been released by public institutions. The origin of many of the privately released cultivars can be traced to purchases from public institutions or selection by private breeders from breeding populations or cultivars developed by public institutions. Of the 10 hybrids, all were marketed by private companies, however, most of these hybrids were produced using at least one publicly developed cultivar as a parent. Often, both parents of a privately marketed hybrid are/were public cultivars. Detailed information concerning which cultivars were produced on large acreages in the SRWW region in 1984 is summarized by Sigenthaler, Stepavich, and Briggle (1986), however, the information contained in the report is rapidly becoming obsolete and the survey, previously conducted every five years by the Statistical Reporting Service, U.S. Department of Agriculture, has been discontinued.

White Wheat. Fifteen Western and 8 Eastern soft white winter or spring wheat cultivars have been released since 1977. Most of these cultivars were developed by public institutions. Four club wheat cultivars have been released since 1977.

The Evaluation of Wheat Progenies to Advanced Experimentals Pertinent to Release as Cultivars.

Soft wheat breeding lines are evaluated for milling and baking quality at several stages of agronomic development. Entries from each location within a crop year are compared to commercially important cultivars grown under nearly identical conditions. Commercial cultivars are used as standards for comparison with breeding lines. The cultivars are grown adjacent to experimental test lines to minimize the effects of environmental variability. Breeding lines are considered satisfactory if all of the numerous analytical, milling, and baking data are similar to those of the standard varieties. If the qualities of all new varieties are similar to those of varieties being grown, their introduction should cause minimal changes in commercial milling or baking quality when they are extensively cultivated.

The average total development time required to the release of a new soft wheat cultivar is 12 to 15 years. Micro quality determinations usually begin in the F_5 to F_6 generation, followed by larger sample quality tests in the F_7 or later generations. By the time of the final release decision on a new cultivar, 6 to 7 years or more of quality data have been evaluated for samples grown at 1 to 30 locations. Quality data evaluated each year are illustrated in Tables 4-1 and 4-2. Typically lines rated as E or F (usually D as well) in combined quality scores (quality relative to commercial checks) are never released as new cultivars. We should restate here the fact that kernel, milling, and baking quality are only three of a large set of parameters considered by breeders relevant to a final release decision on a new cultivar. A typical wheat breeding program involves a large array of nurseries, varying in plot size, number of entries, number of replications and number of variables recorded. A simplified, stylized example of a typical breeding program is shown in Fig. 4-1 and a few of the many variables examined in a typical advanced entry nursery are shown in Table 4-3. Unique problems affecting wheat breeding and production exist in every region of the U.S., however, it is beyond the scope of this report to discuss those unique to the SRWW and SWWW regions.

Table 4-2. Milling and Flour Analytical Data, and Soft Wheat Quality Scores for 1986 Early Generation Nursery Entries from Wooster, Ohio.

Lab No.	Entry	Milling Quality[2] Score	Baking Quality[2] Score	Comb. Quality[2] Score	Adj. Yield %	Flour Protein %	Micro[3] AWRC %	Softness Equiv. %	Allis Equivalents[5] ESI[4] %	Break Flour Yield %	Flour Yield %
	Standard[1]	100 A	100 A	100 A	69.9	11.4	54.1	67.0	16	42.9	72.6
	Benchmark	110 A	100.1 A	100.1 A	74.1	8.3	52.4	57.7*[6]	10.2	35.4	76.8
3005	19777-05	103.8 A	94 C	94 C	70.9	11.8	54.3	60.8*	14.6	37.9	73.7
3006	19777-06	101.2 A	88.5 D	88.5 D	70.2	11.9	55.2	58.8*	15.6	36.3	72.9
3007	19777-07	103.9 A	98.9 B	98.9 B	71.0	12.1	52.6	62.3*	14.5	39.1	73.7
3008	19777-10	88.3 D	80.9 E	80.9 E	66.6*	12.3	57.4*	63.9	20.6	40.4	69.3
3009	19777-14	98.4 B	79.7 F	79.7 F	69.4	12	57.6*	62.1	16.6	39	72.2
2010	19777-17	97.1 B	87.2 D	87.2 D	69.0*	12.3	55.8	62.8*	17.2	39.5	71.8
3011	Caldwell	97.5 B	96.7 B	96.7 B	69.1	11.4	54.9	67.4	17	43.2	71.9
3012	19777-23	99 B	100.4 A	99 B	69.6	12	53.3	65.0	16.4	41.3	72.3

---

[1] Standard = average of 5 Caldwell entries.
[2] Quality number classification: A = 100 and greater, B = 95 to 99.9, C = 90 to 94.9, D = 85 to 89.9, E = 80 to 84.9, F = 79.9 and lower.
[3] Alkaline water retention capacity test using 1 g flour.
[4] Endosperm Separation Index (ESI) is a milling index indicating relative ease with which the endosperm is separated from the wheat bran.
[5] Estimates from Quadrumat Junior mill for the Allis-Chalmers mill.
[6] Values that deviate (in the wrong direction) from the standard by one $LSD_{0.05}$ are designated with an asterisk (*).

Figure 4-1. Flow Chart for Wheat Breeding Program.

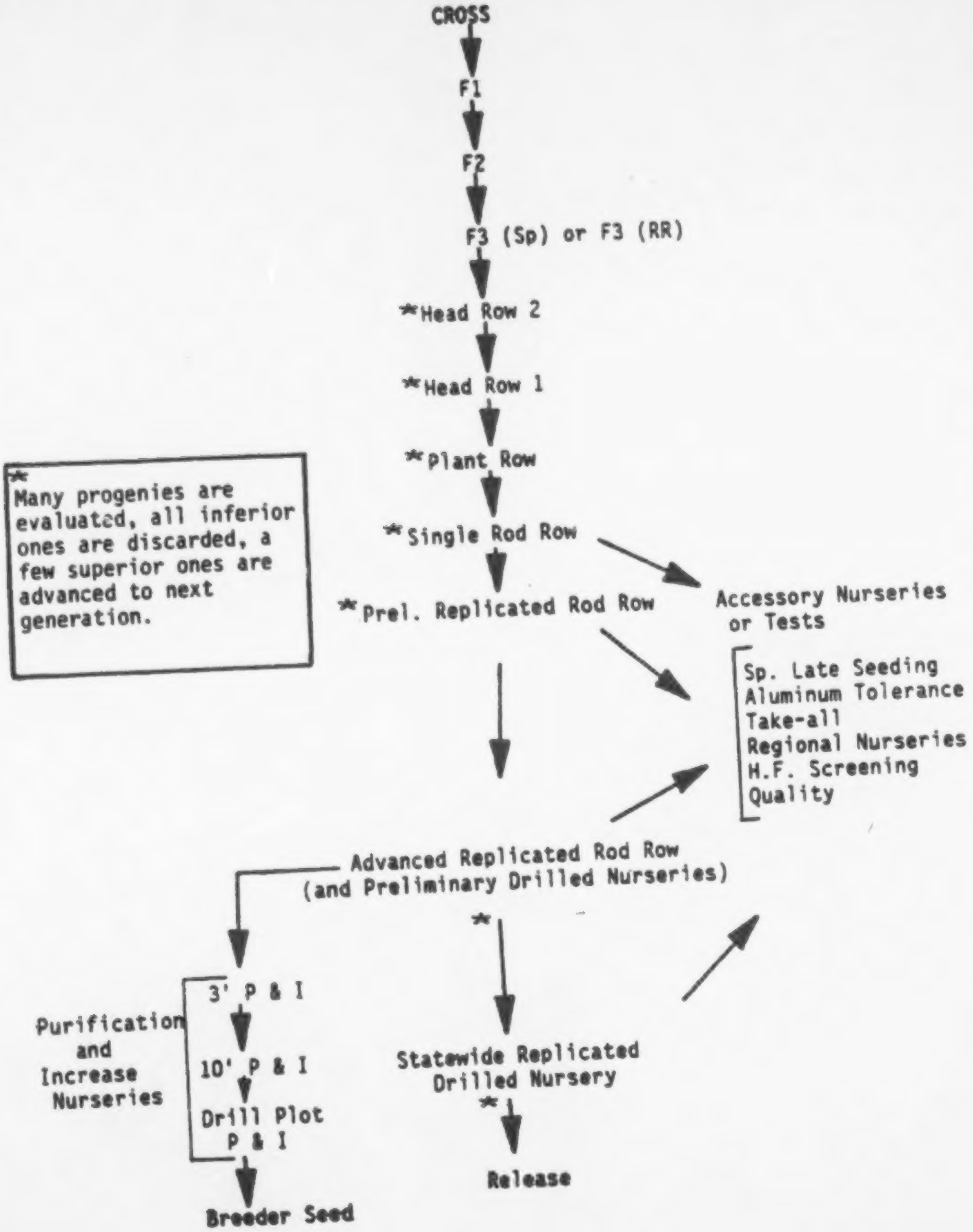
CROSS
F1
F2
F3 (Sp) or F3 (RR)
*Head Row 2
*Head Row 1
*Plant Row
*Single Rod Row
*Prel. Replicated Rod Row
* Many progenies are evaluated, all inferior ones are discarded, a few superior ones are advanced to next generation.
Accessory Nurseries or Tests
Sp. Late Seeding
Aluminum Tolerance
Take-all
Regional Nurseries
H.F. Screening
Quality
Advanced Replicated Rod Row (and Preliminary Drilled Nurseries)
*
Purification and Increase Nurseries
3' P & I
10' P & I
Drill Plot P & I
Breeder Seed
Statewide Replicated Drilled Nursery
*
Release

Table 4-3. Summary of Advanced Entry (Set #1) Yield Trials of Experimental Wheat Lines, Ohio, 1987. (In order by average yield in 4 tests.)

	Yield (bu/A)										
Entry	OARDC (Rod row)	N.Western Br. (Rod row)	Southern Br. (Rod row)	OARDC (Drill plot)	Avg.	Avg.Date Headed (May)	Avg. Pl.Ht. (in.)	Avg. Lodging (%)	Avg. Mildew (%)	Avg. Leaf Rust[1]	Avg. Test Wt. (lb/bu)
OH 389	68.7	57.4	51.2	62.3	59.9	23	33	37	30	15MS	54.5
Cardinal	70.0	52.4	49.1	67.8	59.8	23	37	48	50	3R	55.7
OH 371	66.5	49.7	51.9	68.3	59.1	23	34	26	6	1VR	56.7
OH 343	67.1	50.3	49.9	66.6	58.5	21	37	8	21	15MS	55.9
Caldwell	65.0	57.5	49.1	61.0	58.2	21	34	65	30	1VR	56.1
OH 391	64.9	56.3	46.1	62.8	57.5	22	38	62	50	12MS	56.8
OH 373	63.0	53.7	48.7	64.4	57.5	22	33	42	13	0VR	56.4
OH 382	65.2	52.8	48.6	62.3	57.2	26	38	35	8	2R	53.9
OH 288	62.2	55.5	49.5	60.6	57.0	20	36	43	18	11MR	56.7
OH 372	65.5	48.7	51.1	61.7	56.8	19	39	24	0	2VR	57.8
OH 393	68.3	47.2	41.7	68.9	56.5	24	38	48	11	25MS	55.0
OH 376	56.4	49.0	53.3	65.6	56.1	22	34	22	16	13MR	57.7
OH 369	62.7	47.7	52.8	60.3	55.9	19	34	24	18	1MR	57.0
Becker	56.0	55.1	44.5	67.5	55.8	24	31	31	93	11MR	54.7
OH 312	62.5	46.5	52.5	61.6	55.8	20	34	40	20	1VR	55.3
OH 378	60.4	57.7	40.6	61.4	55.0	24	33	38	40	15MS	55.5
OH 363	59.8	51.6	49.0	59.6	55.0	26	37	21	45	5MR	55.6
OH 379	59.9	55.2	41.3	60.2	54.2	24	33	38	35	17MR	55.6
Tyler	68.9	34.7	43.8	68.8	54.1	23	38	33	8	38S	55.2
OH 362	57.9	57.2	44.0	55.8	53.7	22	36	34	50	15MS	52.8
OH 388	60.3	49.4	48.3	54.9	53.2	24	35	45	6	15MS	55.4
OH 353	57.4	50.2	46.8	57.9	53.1	22	38	38	25	5R	55.8
OH 350	59.3	58.1	39.2	55.2	53.0	24	33	22	25	13MR	55.9
OH 367	62.3	40.6	44.3	62.1	52.3	25	37	40	15	1R	55.9
OH 377	55.2	53.9	37.6	57.7	51.1	24	37	10	50	11MS	57.5
$\bar{x}$	62.6	51.5	47.0	62.2	55.9	23	35	35	27	--	55.8
5% L.S.D.	6.2	8.0	8.2	5.5							

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[1] % - class (VR = very resistant, R = resistant, MR = mod. resistant, MS = mod. susceptible, S = susceptible). Data shown are average for Wooster and Ripley, the only locations with leaf rust in 1987.

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CHAPTER 5

ROLE OF PUBLIC VERSUS PRIVATE WHEAT BREEDERS AND VARIETY RELEASE PROCEDURES

This section will be treated generally over all Classes except the opportunities for private seed companies to develop and sell wheat variety seed are much greater in the Classes having the largest acreage and markets and/or having potential for sale of the same variety product as planting seed for commercial wheat production in foreign countries. The public breeder of the United States considers potential markets in foreign countries primarily on the basis of sale of commercial wheat grain produced from varieties developed for the state employing the breeder.

The wheat breeding departments of four major companies were consulted regarding their policies and input to this section. Three of the companies having breeding programs in all Classes of wheat responded in detail and, because their systems and policies appeared generally similar, a composite of their responses will be used in this section.

Differentiation of Role

The role of both public and private breeder is be to produce the best possible varieties for wheat growers and, presumably, for those using wheat from processor to consumer.

The percentage use of public and private varieties within each Class will be reported in another section if available as last available in 1984 but annual variety surveys funded by the North Dakota State Wheat Commission (Maier, 1987) may be available only for Hard Red Spring and Durum Wheat (see Table 5-1), and a Nebraska (Frederick and Aschwege, 1987)

Table 5-1. Percentage of Hard Red Spring and Durum Varieties Planted in North Dakota in 1980, 1982, 1984, 1986 and 1987.

HRSW Variety	1980	1982	1984	1986	1987 Pct.	1987 Acres Planted
	- - - Percent - - -					
Stoa	-	-	-	28.1	29.3	1760.7
Len	1.7	27.6	20.6	18.4	19.7	1184.8
Marshall	-	1/	21.5	13.5	16.6	995.4
*Pion.2369	-	-	1.1	5.5	6.1	366.0
Coteau	5.9	11.9	6.8	3.6	3.7	220.8
Alex	-	1/	10.0	6.0	3.1	183.9
Waldron	18.5	10.3	6.7	4.9	3.0	179.7
Wheaton	-	-	1/	4.0	2.9	174.7
*Norak	-	-	-	1/	2.1	124.5
Butte	22.1	15.5	8.4	2.8	1.6	98.0
Olaf	26.9	14.7	8.0	2.0	1.6	97.1
*Success	-	-	-	1/	1.2	72.3
*Norseman	-	-	-	1/	1.2	69.7
*Leo 747	-	-	-	2.0	1.1	66.8
*West B906	-	-	1/	1/	1.0	61.9
Butte 86	-	-	-	-	.9	52.1
*Oslo	-	1/	5.4	1.1	.7	42.6
*Solar	-	-	-	-	.5	30.2
Guard	-	-	-	1/	.4	25.8
Other & Unknown	24.9	20.0	11.5	8.1	3.3	193.0
All Varieties	100.0	100.0	100.0	100.0	100.0	6000.0

1/ Less than 1.0% included in other and unknown. 2/ Includes: Apex, Columbus, Ellar, Erik, Leader, Lew, Nordic, Walera, Leif, Katepwa, Celtic, Cutless, Buckshot each with less than 0.4%.

Durum Variety	1980	1982	1984	1986	1987 Pct.	1987 Acres Planted
	- - - - Percent - - - - -					(000)
Vic	2.3	36.6	50.4	42.2	43.9	1184.7
Rugby	18.7	15.1	13.3	10.6	14.4	389.5
Ward	37.7	23.2	18.3	13.6	13.7	370.7
Monroe	-	-	-	1.7	8.1	219.5
Cando	11.2	6.0	3.9	3.2	5.7	154.6
Lloyd	-	-	1.8	20.4	5.4	146.9
Medora	-	-	-	2.3	3.5	93.2
Crosby	11.8	10.1	5.7	3.9	2.8	76.9
Rolette	6.2	2.3	2.0	1/	.8	22.5
*Laker	-	-	-	1/	.6	17.3
Other & Unknown	12.1	6.7	4.6	2.1	2/1.1	24.2
All Varieties	100.0	100.0	100.0	100.0	100.0	2700.0

1/ Less than 1.0% included in other and unknown. 2/ Includes: Kyle, Wakona & Wells each with less than 0.5%.

Varieties with asterisk preceding are private varieties. Source: Dakota Gold 5(1):1-2, August, 1987.

survey for hard red winter wheat varieties, for several recent years (see Table 5-2). Farmers of North Dakota and Nebraska now grow primarily publicly developed wheat varieties. The Statistical Crop Reporting Service, USDA, makes wheat variety surveys only at 5 year intervals, and recently has announced their intent to cease wheat variety surveys because of budget restrictions. Information on proportional use of public vs. private wheat varieties will be difficult to obtain without variety surveys. Each company will know its market share, of course.

Further, regarding "roles", the public wheat breeder employed at Land Grant Universities usually has a "joint appointment" with teaching, training of graduate students, and extension duties in addition to the research assignment to breed better wheat varieties and conduct publishable genetic studies on wheat. The private wheat breeder primarily does field research but also may have administrative and market promotion duties in some seed companies.

Rationale for Differentiation.

The impetus to produce new varieties, or at least "obvious return on investment", perhaps is not perceived so urgent from the farmer and commodity group "stockholders" of the public wheat breeder as from the company stockholders of the private breeder. Also, the product promotional divisions of private seed companies are perceived by some public breeders and farmers to need a new variety to promote annually thus influencing the private wheat breeder to release new varieties more frequently . However, private wheat breeders respond that this perception is incorrect and that product promotion or marketing divisions may prefer to promote and sell a wheat variety for several years as more efficient of marketing resources, seed increase

Table 5-2. Percentage and Acreage of Hard Red Winter Wheat Varieties Planted in Nebraska 1981 to 1987, Inclusive. (An Asterisk* Precedes the Name of Private Developed Varieties)

Variety	1981	1982	1983	1984	1985	1986	1987 2/
	Thousand acres						
Brule	—	3/	73	643	850	658	494
Siouxland	—	—	—	—	3/	64	375
Centura	—	—	—	3/	31	158	314
Centurk & Centurk 78	1,266	1,305	1,120	899	533	437	272
Colt	—	—	—	—	3/	80	93
Buckskin	210	171	148	141	156	123	84
Scout & Scout 66	573	409	271	205	133	115	76
*Agri Pro Hawk	—	—	20	112	117	109	74
*Agri Pro Rocky	51	152	179	141	102	76	38
*Agri Pro Wings	69	143	185	269	101	59	38
Newton	36	—	62	80	39	35	33
Bennett	126	177	131	99	65	30	27
Vona	30	107	120	166	99	73	27
Gage	135	97	95	67	65	23	21
Arkan	—	—	—	—	—	3/	20
Other Public Varieties 4/	462	452	373	234	174	105	86
Other Private Varieties	42	37	23	144	135	155	128
State	3,000	3,050	2,800	3,200	2,600	2,300	2,200

1/ Weighted by acres planted to winter wheat in each Crop Reporting District. 2/ Summary of 1,232 Fall Crops Acreage and Production Survey reports of wheat varieties planted for 1987. 3/ Included in "Other Public Varieties." 4/ Other public varieties planted for 1987 include Cody, Dawn, Eagle, Hail, Homestead, Lancer, Lancota, Larned, Lindon, Nebred, Norkan, Redland, Sage, Sandy, Scoutland, Tam 104, Tam 105, Tam 107, and Warrior.

Variety	1981	1982	1983	1984	1985	1986	1987 2/
	Percent						
Brule	—	3/	2.6	20.1	32.7	28.6	22.5
Siouxland	—	—	—	—	3/	2.8	17.0
Centura	—	—	—	3/	1.2	6.9	14.3
Centurk & Centurk 78	42.2	42.8	40.0	28.1	20.5	19.0	12.4
Colt	—	—	—	3/	3/	3.5	4.2
Buckskin	7.0	5.6	5.3	4.4	6.0	5.4	3.8
Scout & Scout 66	19.1	13.4	9.7	6.4	5.1	5.0	3.5
*Agri Pro Hawk	—	—	.7	3.5	4.5	4.7	3.4
*Agri Pro Rocky	1.7	5.0	6.4	4.4	3.9	3.3	1.7
*Agri Pro Wings	2.3	4.7	6.6	8.4	3.9	2.6	1.7
Newton	1.2	—	2.2	2.5	1.5	1.5	1.5
Bennett	4.2	5.8	4.7	3.1	2.5	1.3	1.2
Vona	1.0	3.5	4.3	5.2	3.8	3.2	1.2
Gage	4.5	3.2	3.4	2.1	2.5	1.0	1.0
Arkan	—	—	—	—	—	3/	.9
Other Public Varieties 4/	15.4	14.8	14.0	8.7	6.7	4.5	3.9
Other Private Varieties	1.4	1.2	.1	3.1	5.2	6.7	5.8

1/ Weighted by acres planted to winter wheat in each Crop Reporting District. 2/ Summary of 1,232 Fall Crops Acreage and Production Survey reports of wheat varieties planted for 1987. 3/ Included in "Other Public Varieties." 4/ Other public varieties planted for 1987 include Cody, Dawn, Eagle, Hail, Homestead, Lancer, Lancota, Larned, Lindon, Nebred, Norkan, Redland, Sage, Sandy, Scoutland, Tam 104, Tam 105, Tam 107, and Warrior.

Source: A.L. (Roy) Frederick, Director, Nebraska Department of Agriculture and Jack Aschwege, State Statistician, USDA, National Ag Statistics Service.

procedures, and seed conditioning facilities.

Release of Wheat Varieties

General Information

Both the public and private wheat breeder attempt to create or produce wheat varieties excelling for both agronomic and end use characteristics, i.e., "wheat grain quality," without sacrificing end-use value to highest possible grain yield. The public wheat breeder has the guidance of policy of the State Agricultural Experiment Station employer, regional policy and national policies. These public policies are developed via the guidance of the national policy on release of seed-propagated plants entitled "A Statement of Responsibilities and Policies Relating to Development, Release and Multiplication of Publicly Developed Varieties of Seed-Propagated Crops" of the Experiment Stations Committee on Policy (ESCOP), seeds in this case, signed by the State Experiment Stations, the ARS and SCS of USDA, and the National Council of Commercial Plant Breeders (Beattie, 1972). However, the policy is guidance only and states may and do vary from this policy. Private wheat breeders are influenced by the principles of the public policy and have systems within their companies guided by the wheat breeders, the quality evaluators, marketing divisions, and company management to achieve the same results. Further, the National Council of Commercial Plant Breeders also has signed the national ESCOP policy on release of seed-propagated plants.

The principle applied on whether to release superior experimental genotypes is basically whether the candidate for release is better in one or more agronomic or quality characteristics as compared to acceptable standards "check" commercial varieties in use) and more or less equal in all other characteristics. However, "farm programs," while attempting to control acreages of surplus crops, "give a signal" to the farmer and the wheat breeder justifying advancement and release of experimental progenies having unusually high grain yield and good other agronomic and end use characteristics but perhaps not meeting minimum standards for every agronomic and end use characteristic. The motivation to make such variety releases is based on rewards for "average yield records," loans and/or deficiency payments on "wheat as wheat" without regard to end use quality, or even numerical grade and Class or Subclass. Often, the cash grain market itself appears to provide no reward for farmers who produce wheat varieties with outstanding characteristics for end use quality. Sometimes, a wheat variety release decision may be based on highly superior yield with decreased emphasis on end use quality. However, premiums for end use quality are known in the system, e.g., for high protein, above 12% on 12% moisture basis, of Dark Northern Spring, and for the Subclass White Club. The wheat breeding system, the farmer and the market respond knowingly and positively to such premium opportunities.

Specific Release Procedures for Wheat Varieties

This section is outside the "public vs private" role, however, the principles involved in release of public and private wheat varieties are similar.

The Public Policy. The release policy of a public wheat variety from a State Agricultural Experiment Station with or without cooperation of ARS, USDA, has the guidance of the national ESCOP Seed Policy statement "A Statement of Responsibilities and Policies Relating to Development, Release and Multiplication of Publicly Developed Varieties of Seed-Propagated Crops," (Beattie, 1972) regional policies on seed release (Carter, 1964) such as those developed by NCS-1 (North Central Regional Committee on Seed Policies and Practices), and state seed release policies developed by each state (Carter, 1964) under the NCS-1 activities. These national and regional policies are guidance only, and states may and do release new varieties and germplasm following their current policies. Variety release policies have been quite similar in past years, but some North Central states now have, or plan to have, somewhat different policies than those used in the past. The reader is referred to Proceedings of State Agricultural Experiment Station Plant Variety Release Workshop, Feb. 9-11, 1987, Lansing, Michigan (Carter, 1987), and Proceedings of the North Central AOSCA Conference, June 8-9, 1987, Lincoln, Nebraska (Carter, 1987; Lechtenberg, 1987). Many "institutional influences" discussed at the Michigan and Nebraska conferences will affect discussion and considerations in release of publicly developed wheat varieties in the near future.

Variety release procedures and policies of the private seed company reflect only company policy with perhaps institutional influences of the National Council of Commercial Plant Breeders and the American Seed Trade Association, and policies and procedures of public institutions. The release decision mechanism is via the wheat breeding team and company management more or less parallel to the public procedure, realizing that a company product must generate profit to recoup development and marketing costs.

An introduction leading to the events creating a new public wheat variety by public or private breeders may be informative to the reader.

(1) A wheat breeder probably with supporting scientists and technical personnel is hired and provided the financial and physical resources to develop a variety superior to those then in commercial use. (2) Crosses are made of desired parents and progenies evaluated in micro and macro tests for 5 to 8 years for major and minor agronomic and end use characteristics compared to a "standard check or control", usually a commercial variety occupying a significant acreage of the Class involved. (3) The breeder as leader of the breeding team evaluates and justifies release and naming of a superior experimental progeny. (4) A Variety Release Committee composed of scientists of the wheat breeding team and their department chairs, appropriate extension specialists, representatives from appropriate commodity and regulatory agencies, and the Experiment Station Director recommends release or rejection of the wheat experimental line proposed for release. (5) The final decision on a release may, if the Release Committee cannot agree, be made by the Director of the State Agricultural Experiment Station. (6) The AES usually is considered the "breeder of record" for purposes of Plant Variety Protection, royalties, etc. (7) Basic seedstocks of the new variety are increased to Foundation seed by the AES or a quasi-nonprofit agency for the public variety. (8) Elite growers increase the new variety to Registered and Certified seed for use by commercial crop growers. (9) The breeder deposits a small amount of breeders seed in the Germplasm Bank at the National Seed Storage Laboratory, writes a descriptive Registration article about the new variety for the Crop Science journal, maybe prepares information and an application for Plant Variety Protection, and writes a news release to inform the public who will use the new variety.

The Variety Release Policy of Four Major Private Seed Companies.

The generalized development and variety release policies of four major seed companies who replied to inquiries about their policies and procedures on variety development and release are discussed below.

1. The wheat breeder makes hybrids of desired parents and progenies are evaluated for various agronomic and end use characteristics. Most of the hundreds of progenies or "children" from the original "cross" of the two parents are discarded at each testing stage but a few superior progenies are selected and advanced after several generations as worthy of further evaluation.
2. A Preliminary Test is conducted of apparently superior wheat progeny lines at four locations, one year, and each entry is evaluated for agronomic and end use characteristics. Many wheat lines are discarded as not worthy of further testing.
3. An Advanced Test is conducted at 8 locations, one year, with continued evaluation as in #2 and further discard of some lines, retention of the most superior lines.
4. Elite Testing is conducted at 16 locations for two years with continued agronomic evaluation and end use quality evaluated at both the private company quality laboratory and at independent quality laboratories, for example, in Class end use quality laboratories or private or public agencies and/or cooperatively with the milling industry, e.g., the flour and bread evaluation by the Spring Wheat Quality Advisory Committee (SWQAC).
5. Wheat progenies (lines) excelling in the Elite Testing receive Precommercial Nomination based on two years of Elite Testing

and satisfactory end use quality scores. A Committee of Director of Research, Crop Director, Cereal Chemist, Breeder(s), and Crop Marketing Analyst accept the variety as precommercial if all agronomic, disease, and quality end use data are satisfactory.

6. A third year of Elite Testing is conducted including evaluation of an independent agency such as SWQAC. Breeders seed is produced to continue seed increase advancement, if approved.
7. The same Committee as listed in No. 5 evaluates again and, if approved, Foundation seed is produced and sales divisions are notified. The Plant Breeding Division retains control of the prospective variety. If release is approved, seed is distributed to sales divisions for registered and certified seed production. The Director of Plant Breeding and Crop Director sign the official release announcement.
8. A Commercial Number (equivalent to variety name) is assigned. Seed is conditioned at company plants and allocated to District Sales Managers who establish sales goals for each sales area. Farmer dealers sell the seed. The company provides advertising support.

Breeding for Specific Markets

Both public and private breeders develop varieties within the various Classes for the traditional markets of those classes as listed below:

1. Hard red winter wheat for the white pan bread market;
2. Hard red spring wheat for the hearth bread, blending for specialty breads, and the pan bread market;
3. Soft red winter wheat for cookies, cake, noodle, breadings, gravies, crackers and other markets;
4. Durum wheat for the pasta market but strong gluten wheat can be used for bread making;
5. White wheat for the cake, cracker, and noodle markets with the Subclass White Club or the club component of Western White holding some special niche in the market.

Wheat breeders have developed wheat varieties to fit the above end uses very well for 75 or more years, although the "state of the art" and knowledge of exact quality traits needed and their inheritance seem to be less well known in the soft red and white wheats than in the other classes as described in another section. Present end use quality seems to have fit the needs of the buns for the fast food industry, the crust for the pizza industry, the base for the variable breads other than white pan bread, the thickenings for various uses, etc. No wheat breeder, cereal chemist, public or private administrator, and no commodity organizations have come forth with a truly new use for the endosperm components of the wheat kernel as processed to flour, semolina, or other raw materials. Wheat breeders in California, Kansas, Colorado, and Montana at least have developed, and continue to improve, hard white wheats suitable for pan bread or "family flour" on whole wheat products with white bran having potential domestic and export use. (See Future Outlook, page 211 for more details). However, new uses or new foods may be devised or developed, the wheat plant may have the diversity, and the wheat breeder will have the skill to modify the wheat kernel for a new use. Or, genetic engineering might modify the wheat kernel some way leading to a new use.

Some private wheat breeders foresee a situation where specific wheat varieties may be desired and produced for specific locations or markets for the farmer, broker or processor--such varieties would be produced, harvested, marketed and processed "variety identification preserved or guaranteed" as now done with many malting barley varieties. Further, more study of potential market areas and probable share of the market for any new wheat variety may refine wheat production and marketing for end use more than in past years.

The public breeder generally breeds wheat only for the state of his/her employment or for regions of that state having unique environmental characteristics, e.g., variable soil type, pest hazards, precipitation variables, etc., while the private breeder of the largest companies may be charged with developing wheat varieties for a state, several states, and hopefully a variety adapted to wheat growing regions in foreign countries where a specific company may have a subsidiary.

Funding of Wheat Improvement Research Programs

Public Funding

Public funding for wheat improvement research comes from state legislatures and the Federal Congress (taxpayer support), from gifts and/or grants from commodity grower organizations or agribusiness, foundation seed royalties and minor sales of discarded seed. This funding often is closely related to the economic health of the state and of agriculture if agricultural income is a major component of new wealth in a state. The funding was relatively stable, perhaps increasing gradually in the 1950-80 period, but has stabilized or decreased in purchasing power since 1980, and usually does not respond quickly to sudden needs or to perceived opportunities for research and development. The funds are used both for so-called applied research to develop new varieties and for basic research to develop basic knowledge and wheat germplasm. The public funding for wheat research comes primarily from state legislatures and from the Federal Congress, the latter as so-called Hatch funds, varies significantly by states. This public funding may vary from as little as 35% to as much as 75 to 80% of the total research budget for wheat improvement and other research among State Agricultural Experiment Stations. The remainder of the funds comes from gifts, voluntary or competitive grants, commodity checkoffs, etc. Some states now believe that they must charge royalties on seed of new varieties sold to help fund plant breeding research as competition increases for the use of limited public funds. Charging royalties for publicly developed varieties appears to have generated variable response from farmers and from both public and private agencies.

Private Funding

Private funding for wheat improvement research is corporate funding intended to produce a product to sell for a dividend or return on investment. The financial support or resources may be more generous relative to public funding, and are more responsive to sudden needs and opportunities to exploit an area or product, but can be decreased or terminated very suddenly if return on investment is inadequate, or if other investments may provide a greater rate of return. For example, many large and small seed companies initiated breeding programs on wheat soon after passage of the Plant Variety Protection Act, but wheat breeding did not produce profitable returns for most of them, and only a few large seed companies now have breeding programs on conventional wheat varieties and/or hybrid wheat. If the private company has a profitable year or financial period, the private plant breeder may receive a "bonus" above salary in variable form as direct financial reward, gift of company stock, opportunity to buy stock at a special price, or in some other form. The public wheat breeder of the State Experiment Stations or ARS, USDA has not received bonuses or a share of royalties, if charged, in the past but a few states now share royalties with the breeder or plan to do so.

Future Roles of Public and Private Wheat Breeders.

Some recent surveys are available on this topic, i.e., public vs. private wheat breeding. The debate is whether the public State Agricultural Experiment Station should develop basic germplasm only and the private company use, finish developing, and sell the variety or hybrid to the farmer-user, a system more or less followed in Europe. The American Seed Trade Association and National Council of Commercial Plant Breeders would appear to support a system in which public scientists develop germplasm and private companies "finish" and sell varieties or hybrids, but concede that the public breeder should breed and develop varieties of minor crops in which private company investment is not justified. But, private companies also concede that the public breeder and Universities must develop varieties of major crops to maintain viable and productive breeding programs for the research, teaching and extension functions.

Many, or maybe most, public wheat breeders and administrators of State Agricultural Experiment Stations and farmers in major wheat growing states maintain that the public Land Grant University must breed and release finished varieties and also develop basic wheat germplasm because (1) the farmer demands public varieties as a return on tax dollars invested in research, and the "return on investment" often has been calculated as 50- to 100-fold comparing public wheat research investment to additional farm income realized from new superior varieties; (2) new young plant breeders can be trained only in plant breeding programs of the Land Grant Universities; (3) public and private wheat breeders and cooperating cereal chemists maintain end use quality characteristics needed to retain domestic and international markets better than either might alone; (4) the public plant breeding program is more long term and stable, and not vulnerable to termination or sale to another company on short notice; (5) the wheat breeder at the Land Grant University usually has more basic scientists as cooperators on a "wheat breeding team," e.g., plant pathologist, cereal chemist, cytogeneticist, molecular biologist, biochemist, agricultural economist, and the agricultural extension information feedback system available as consultant-cooperators, hence is more likely to produce a superior product, and/or can develop, evaluate and maintain a much more diverse and long-term germplasm pool; (6) public breeders and public varieties are needed as strongly competitive forces with private wheat breeders to provide and maintain standards for agronomic performance and end use quality in the varieties produced by farmers and processed by industry to the consumer product; (7) seed of public varieties usually is available at a lower cost than that of private varieties due to lower marketing and promotional costs but partly because taxpayers have invested to provide the basic resources at the University and Agricultural Experiment Station system; (8) farmers wish a choice of both public and private wheat varieties because they do not wish to have only public or private wheat varieties available as the only source of seed, nor do they wish regulations that might prevent their producing and using their own seed from whatever original source; some private wheat breeders believe that the competition of private plant breeding has stimulated many public breeding programs to be more aggressive, innovative, and productive of both varieties and improved germplasm to the benefit of the wheat industry and the consumer; and (9) wheat growers, the wheat processing industry, the general population and the United States government should be aware that several large and small private companies in the United States producing wheat seed and seed of other crops now are partially or entirely owned by foreign or multinational companies not controlled by private families or stockholders in the United States. It may be assumed that citizen-consumers of the United States do not wish all new wheat variety releases or the wheat processing industry, producing our most basic carbohydrate food, controlled outside the United States. Domestic or foreign monopolistic control of any industry, e.g., wheat, corn, coffee, tea, cacao, petroleum, or any other product is not in the best interest of the consumer in the United States, and would be contradictory to our U.S. policy of inexpensive food. However, the cost of planting seed alone, under any forseeable system of production or market control is foreseen by the private seed industry as a negligible cost to the eventual consumer of food from crops.

Re future roles, the issue of conventional varieties vs. wheat hybrids should be discussed. The Agricultural Experiment Station, North Dakota State University, Fargo, ND, has the only public hybrid wheat program now of any significance. At least six private seed companies (personal communication) have hybrid wheat programs and only private wheat hybrids are being sold, i.e., no public wheat hybrids are available for sale. The success of the systems of cytoplasmic-genetic male sterility vs. male sterility induced by chemical hybridizing agents may influence the significance of the relative use of hybrid wheat in the future. The chemical hybridizing agents (CHA) definitely will be of great value in construction and evaluation of many more hybrid combinations than possible otherwise, regardless of the CHA use to produce commercial wheat hybrids. Wheat hybrids for extensive commercial use must provide adequate economic reward to the developers and users or wheat hybrids will not be used. The farmer must purchase hybrid wheat seed each year, therefore successful development of hybrid wheats would extend and stabilize greatly a commercial wheat (hybrid) seed industry. Some breeders believe that wheat hybrids will become necessary for the United States to remain competitive in world markets.

The genetics of hybrid wheat related to grain quality is not well developed other than the end use quality of seed produced on F_1 hybrids has been found to be intermediate between the end use quality of the male and female parents. Probably private seed companies or a contractual arrangement among a seed company, a chemical company and a State Agricultural Experiment Station will place hybrid wheat in the fields of farmers and onwards to commercial processing in the future.

The Affect of Patenting, Plant Variety Protection and Licensing

These terms require brief definition and cannot be discussed in detail, nor are they all pertinent to the topic of this paper. The Plant Variety Protection Act of 1972 (Blum, 1972) required seed certification of self pollinated crops such as wheat if sold or offered for sale. Thus, a farmer-grower could use home grown seed to seed the next crop but could not offer it for sale unless certified. The private companies and some public agencies use PVP via application to, and approval from, the PVP agency of the USDA and assess a royalty on each bushel of certified seed sold as protected via PVP to recoup cost of development of the variety and some profit for stockholders. The principle of PVP has little if any pertinence to the topic of this paper other than assurance of genetic purity and the inherent grain quality of varieties certified via PVP.

A wheat variety probably is not sufficiently genetically pure to justify or be defended as patentable as is a vegetative clone or plant part such as the bud from a rose plant. The patenting of a single gene such as one imparting adequate lysine (an essential amino acid in which wheat is low), or immunity to a specific herbicide used to kill weeds in the wheat field is under much scrutiny by the public and scientists now and cannot be discussed adequately in this paper.

Licensing of wheat varieties, as is done in Canada, implies the establishment of a government body(ies) to determine market acceptance of a new variety throughout the variety development, production and marketing system. Also, licensing implies the establishment of the characteristics of a standard control variety having the desired market characteristics. The licensing principle applies to "wheat breeding issues related to grain quality." Licensing of wheat varieties as done in Canada is considered by wheat breeders in the United States as excessively restrictive to most rapid advancement in wheat breeding because of the limitation on use of diverse germplasm by the wheat breeder to incorporate new or superior characters for improvement of agronomic and end use characteristics. Further, licensing implies the control of marketing from the farm to the eventual domestic or foreign processor, a principle resisted by the marketing system of the United States and society in general. A benefit of licensing as used by Canada does have one advantage of ensuring uniformity of the wheat raw material in the market place for both domestic processing and processing by international customers. Uniformity of wheat raw material is a high priority of domestic millers in the United States too according to Robert L. Morris of Continental Banking, St. Louis, Mo., Tony Hoebelheinrich, ConAgra, Omaha, Nb., and Simon Jackel, Technical Industries, Westport, Ct. expressed at the 1986 End Use Conference at Fargo (Watson, 1986). However, the farmers and wheat breeders of both the United States and Canada consider the restriction of a licensing system to impede breeding progress excessively based on discussion at the End Use Conference (Watson, 1986), SWQAC meetings (Teigen, 1988), and others.

The above statement fits the public policies of the North Central Region, more or less, and the Southern, Northeastern, and Western Regions, based on my inquiry of and responses from Directors-at-Large of the four regions.

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CHAPTER 6

WHEAT BREEDING TECHNOLOGY

Introduction

Public and private wheat breeding programs in the United States annually release several dozen wheat varieties, each representing 8 to 15 years of research. This genetic improvement of wheat germplasm involves highly refined, dynamic systems of breeding, selection, and testing. The organization of these programs, their goals, and the testing procedures used to evaluate candidate varieties addresses a broad spectrum of breeding problems which have been defined through the cumulative knowledge and experience of wheat breeders and geneticists, plant pathologists, cereal chemists, entomologists, other crop scientists, and, finally, of farmers who grow these varieties and sell the wheat produced.

Most of the principal wheat-growing states have had wheat improvement programs for more than 60 years and some for more than 80 years. The accomplishments of these programs are impressive, translating into billions of dollars of value to the U.S. economy annually. From 1958-60 to 1978-80 (three-year averages), for example, U.S. wheat yields increased from 25.1 to 33.1 bushels/acre, a 32% increase. Comparisons from regional nurseries indicated a 17% genetic gain, accounting for about half of the total yield increase or 0.2 bushels/year genetic gain (Schmidt, 1984). Production technologies, including the use of fertilizers, herbicides, pesticides, cultural practices, and farm machinery, accounted for the other half of these yield increases.

The other authors of this publication, discussing the five U.S.

wheat classes, have listed the specific quality traits and attributes desired in commercial wheat varieties and have described why these traits are important and how they are selected in a breeding program.

This chapter is an attempt to provide a more general perspective of wheat breeding by describing some of the capabilities, methodologies, and limitations of current wheat breeding technology. The chapter includes aspects of current knowledge of wheat genetics and cytogenetics and their potential impact on wheat improvement, particularly recent research on the identification and genetics of seed storage proteins, and, finally, how several newer (future) technologies may affect future progress in wheat breeding.

Current Wheat Breeding Methodology

The Germplasm Base

The goal of wheat breeding is genetic improvement of germplasm. Germplasm, to the wheat breeder, is a descriptive term which can be used in several contexts. The germplasm of a single breeding program, that is, all plants and lines currently under selection and evaluation, typically numbering several hundred thousand, is considered the program's principal resource. The project's physical and financial resources are used to select and to test within this germplasm base. In a mature, long-term wheat breeding program, this germplasm base has a history of many cycles of crossing and selection for performance and adaptation to the targeted growing region.

The next level of germplasm which a breeding program uses extensively is varieties and elite lines from other wheat breeding programs, usually within the same wheat class and in the same wheat-growing region. Through various cooperative uniform regional nurseries, each participating breeding program can evaluate its newest, elite lines (from five to ten lines per program) each year in many environments. In 1986, for example, the uniform southern hard red winter nursery, with 46 elite lines entered, was grown at 31 sites in 13 states. Other wheat-growing regions have similar cooperative nurseries.

These cooperative nurseries, which allow breeding programs to evaluate one another's best lines and to incorporate the germplasm of these lines as parents into their own germplasm, can be credited to a substantial degree with the steady genetic improvement of U.S. wheat varieties. This free mutual exchange and use of superior germplasm by breeders may change significantly should genes of food crops be patented extensively in the future.

Next, several levels of germplasm, which breeding programs use infrequently, often can contribute significant new genes for disease resistance and agronomic traits to a program's germplasm. The U.S. World Wheat Collection, with more than 40,000 entries, contains germplasm from virtually every wheat-growing environment in the world, including thousands of older varieties and "land races" as well as recently released varieties. Several other countries have similar, though smaller, germplasm collections. Also included in this category are current varieties and elite lines from breeding programs in Australia, Africa, Asia, Europe, and South America which are exchanged regularly with U.S. breeding programs, but may fail to be included in the national germplasm collection.

In addition, wheat has several wild and semi-wild relatives which extend its potential germplasm base substantially. These relatives include nine diploid (2n=14) chromosomes and 15 tetraploid (2n=28) and hexaploid (2n=42) wild or semi-wild Triticum species which are indigenous to the western Mediterranean and Asia Minor regions. Research on these species has provided knowledge about wheat evolution and insights into its basic genetic organization. Several important genes for disease resistance and other traits have been transferred from these species to cultivated wheat.

The purpose of germplasm collection and maintenance is to preserve genetic variation, the sum total of all genes for all traits found in wheat and its relatives, both known and unknown, to ensure future genetic gain. The question of adequacy of the germplasm base also is partly one of knowledge--an understanding of genetics, the recognition of genes affecting specific traits, and how best to manipulate these genes.

Genetic Variation

Plant breeding can be defined as the controlled creation and management of genetic variation with genetic improvement as the goal. Like the term germplasm, the meaning of genetic variation as plant breeders use it is difficult to convey fully to laymen, who have not had the same opportunities to create variation by crossing diverse parents, to examine variable populations of plants in the field, and, subsequently, to observe how selection can change these populations.

The genetic variation in a program's germplasm permits selection of lines superior to current varieties for one or more traits. Generally, variation exists among plants or lines (genotypes) for every trait being selected in a wheat breeding program, usually including 20 or more quality traits. The degree of variation differs for each. Typically, the breeder seeks to maintain high favorable mean values for most traits and, for that reason, tries to limit the extent of "undesirable" variation.

The breeder uses either empirical or statistical measures to determine the average value of the trait (mean), how the trait varies (phenotypic variation), how much of this variation can be attributed to environmental causes (environmental variation) and to the genotype of the plant (genotypic variation). The degree and kinds of genetic variation in the germplasm and the probable response to selection can be determined experimentally. However, wheat breeders usually judge from experience and familiarity with the germplasm.

The Setting of Goals: Selection for Many Traits

Perhaps what best characterizes wheat breeding objectives is the number of traits evaluated, each controlled by several to many genes. Elite breeding lines have been evaluated for 10 or more agronomic traits, including grain yield, plant maturity, and plant height; for resistance to six or more pathogens, including stem rust, leaf rust, and foliar diseases; for resistance to insects; and for the 20 or more quality traits listed for each wheat class.

The challenge to the breeder is to develop strategies to manage the logistics of testing thousands of lines, eventually evaluating elite lines for more than 40 traits.

The superior variety released this year is the result of breeding goals established 10 or more years ago. Priorities are set first by what wheat breeders, plant pathologists, cereal chemists, and entomologists view as genetic impediments to total crop performance, including processing quality and potential disease or pest threats.

In addition, farmer problems in planting, growing, harvesting, and selling the crop, specific quality attributes the processors need, the discovery of new genes or gene systems, new evaluation procedures and selection techniques, and new equipment all are involved in setting goals and priorities.

Each breeding program places different priorities on various goals according to the status of its own germplasm, its resources and technical capabilities to test germplasm, including its capacity to conduct quality tests and its perception of what traits will most influence farmer acceptance of a variety.

Wheat breeding goals must be realistic, and compromises must be made. Increasing yield and certain quality traits simultaneously can be difficult. Genetic advances in yield often have preceded improvements in quality. But, subsequently, quality improvement at the new yield levels is evident in currently released varieties.

Plant breeding progresses slowly, by increments in many traits, which cumulatively over the years improves crop performance.

Implementing these goals is continuous during the breeding process, although three distinct steps can be identified: 1) the selection of parents; 2) the relative emphasis (selection differential) placed on the 40 plus agronomic and end use traits during generational advance and testing of lines; and, finally, 3) release decisions where attributes of a small group of elite lines (advanced experimentals) are compared critically to choose the "best" of these lines. Quality issues, often including yield versus quality questions, are involved in each step.

Goals guide wheat improvement, regardless of what technical innovations are used. Technological innovations may make achieving quality goals easier, but certain innovations which improve crop performance actually may decrease quality. A breeding program that now releases poor quality varieties probably will not use technical innovations to release good quality varieties in the future.

Choosing Parents for Potential New Wheat Varieties

The implementation of goals begins when breeders choose parents for the "crosses" (hybridization of two parents) they make each year. Each cross is made to achieve a more desirable level of one or more of the parent's traits in the progeny. How frequent a variety or line is used as a parent depends on what priority the breeder places on attributes that variety or line possesses. A program that stresses high quality will use at least one high-quality parent in most of its crosses. A line that possesses a gene or genes for resistance to a new race of a pathogen that threatens wheat production will be used as a parent in many crosses even if the line is unadapted or has poor quality. Elite new lines and successful new varieties are used as one parent in a high proportion of crosses because they typically best fulfill the program's breeding goals.

Extensive, detailed data on all quality traits are particularly helpful when choosing parents for crossing. The annual quality reports from the four Federal Quality Laboratories are valuable aids to wheat breeders for making these choices.

Genetic variation for each of 40 or more traits and the reasons for crossing specific parents to produce segregating populations far exceed the number of crosses a breeding program can manage efficiently. Limiting the number of populations, either before or after crossing, therefore, also becomes a form of setting goals.

The Framework of the Breeding Program

Generalizing about wheat breeding procedures is difficult because there are as many permutations and combinations of managing the logistics of selection and testing as there are breeding programs. Nevertheless, some primary features of wheat breeding can be described by considering the basic framework of generational advance and testing outlined in Table 6-1.

The genetic variation to begin the breeding cycle is obtained through sexual recombination in F_1 plants from 200 to 700 crosses per year (again, depending on the breeding program). Segregating populations of tens of thousands of F_2 plants, each plant a new and distinctive genotype, are grown each year. Genetic segregation continues in the F_3, F_4, and successive self-pollinating generations, diminishing by half each generation as the genotypes of lines become fixed.

In early generations, selection is based on traits which are recognized visually or otherwise are evaluated easily, such as plant maturity, plant height, stem and leaf rust resistance, and general plant appearance. Such selection is considered as fairly subjective.

Selection for each trait further depends on 1) the time required to measure the trait, 2) the number of plots which must be evaluated to obtain a reliable estimate of the line's performance, and 3) the amount of seed required for the test.

Selection for quality in early generations and during preliminary testing is accomplished mainly by using micro-evaluation

Table 6-1. Generational Advance in a Typical Pedigree Wheat Breeding Program.

Season	Generation*	Breeding population size	Selection/evaluation activities
1	Initial crosses	200 to 700 new crosses per year	
2	F_1	200 to 700	Some selection among F_1s based on additional data or phenotype
3	F_2	500 to 2000 plants per F_2 population	Grown as spaced plants, sometimes as bulk populations, Strong selection between populations and for plants within populations, visual selection for easily classified traits
4	F_3	5000 to 50,000 total plant or head rows	Begin line selection, visual selection for easily classified traits, e.g., height, rust resistance
5	F_4	1000 to 5000 observation rows or head rows	Continue visual selection with additional traits, possibly begin protein, few quality evaluations
6	F_5	400 to 1000 lines in preliminary yield trials or observation rows	Testing becomes more quantitative, replicated, multi-location, initial yield data, quality evaluations
7	F_6	150 to 400 lines in yield trials	Similar to F_5
8	F_7	20 to 50 lines in advanced yield trials	Yield trials at several locations, complete quality and disease resistance testing
9-11	F_8	5 to 10 elite lines	Extensive yield testing in state and regional trials, complete disease and quality comparisons to standard varieties, identification of candidate varieties

Finally, seed increase decisions are made during final evaluation stages and at the time of varietal release.

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[*] Filial generation

procedures. Cereal chemists and breeders have devised an array of such tests which correlate with functional processing quality. The research and time that has been devoted to these tests, described in the sections for each of the wheat classes, attests to their importance to breeding programs. Mixograms, cookie tests, and microloaves are examples of tests which can be done using small samples of wheat kernels.

Severe selection among and within populations, practiced during early generations, rapidly reduces the number of lines tested in each successive generation.

Improving the Efficiency of Wheat Breeding

Each breeding program constantly strives to improve the efficiency of its selection and testing procedures and to understand the available genetic variation. The dynamics involve a steady flow of information and data from many sources.

Crossing, selection, and testing decisions are revised and are updated as agronomic, disease, and quality data from the current season's nurseries and area wheat crop are evaluated.

Experimental design, statistical analyses of data, and plot and testing equipment are refined continually. Breeding programs collect enormous amounts of data each year. Much of the data analysis that formerly was done with mainframe computers now is being done with microcomputers. Also, programs are being written which greatly facilitate various organization and data collection activities of the breeding program.

The impact that a new analytical technique can have on selection strategy is shown vividly by the application of near-infrared reflectance spectroscopy (NIRS) to measure protein and moisture percentages. NIRS, developed in the 1970s, is rapid, practical, and inexpensive. With a single NIRS machine, protein percentage can be determined on about 200 wheat or flour samples per day. For a wheat breeding program, this means that early generation selection for protein percentage can become routine, substantially increasing the proportion of later generation lines which have the desired protein level.

Replicated yield trials are expensive to conduct. A breeding program must grow several thousand yield plots each year at several locations. In recent years, development of small plot combines with which one to two yield plots per minute can be harvested while maintaining seed integrity of each plot is one example of how the efficiency of wheat breeding can improve markedly.

Other Quality Considerations

Wheat breeders encounter several breeding situations in which quality can become a problem.

The most common situation is termed correlated response to selection which occurs when selection for one trait causes changes in another trait or traits. The correlated response can be positive or negative, and the degree can vary from slight to very strong. In durum wheat, for example, the gene for glume color is located near to and on the same chromosome as the gene controlling gluten strength. Durum breeders have used this genetic marker effectively to identify strong gluten durum lines.

In the bread wheats, the negative correlation between grain yield and protein percentage that exists in many breeding populations constantly challenges the breeder as he/she attempts to improve grain yield yet maintain protein percentage. The search for genes which increase protein percentage or which improve the quality of the protein is continuous.

Other situations in which quality can be affected adversely involve the introduction of genes from related species. The best known example is the 1B/1R wheat-rye chromosome translocation. The rye chromosome arm introduced into wheat carries valuable genes for disease resistance, but it also can cause problems with stickiness of bread dough. This problem will be discussed later in the paper. Problems with test weight, flour color, and other traits have been associated with an alien chromosome segment introduced for disease resistance in several other cases.

The "Discovery Component" of Wheat Breeding

Although the parents in a breeding program are chosen carefully, and the crosses between them carefully planned, wheat breeding procedures also, in a sense, are designed to manage the "unknown" in wheat genetics. Knowledge is limited about the genetics of many important plant traits: the identity of specific genes, the number of genes that affect the trait, and the way the genes are expressed. The tests to evaluate most traits are functional: for instance, those for flour milling yield, loaf volume, or grain yield. They measure the combined effect of all an experimental line's genes, both known and unknown.

It usually is not recognized how powerful standard wheat breeding procedures are in terms of "discovering" new genes or genotypes which enlarge, sometimes uniquely, opportunities for genetic improvement.

The unknown, unplanned component of a process that continuously introduces new genes into a program's germplasm is large--with sexual reproduction creating populations of plants with tens of thousands of new gene combinations.

A skilled breeder's systematic evaluations of functional performance and careful observation make standard applied breeding a potent means of sorting through the wheat germplasm pool and "discovering" new knowledge. Although such discoveries often are called "fortuitous, " they are, nonetheless, an intrinsic component of current wheat breeding practices that will remain important as breeding programs increase their efficiency in functional testing and managing large breeding populations.

The Timetable of Wheat Breeding and Varietal Seed Increase

An understanding of the timetable of varietal development, testing, and seed increase is required to evaluate past progress in wheat breeding, to plan future research, and to provide a perspective about the possible rates of progress of future research.

The breeding and seed increase schedule for Stoa, a hard red spring wheat variety recently released by the North Dakota Agricultural Experiment Station, is an example (Table 6-2). Greenhouses, off-season winter nurseries, and early, coordinated increases of seed can accelerate this schedule before any release decision is made.

Some future technologies will decrease the period for varietal development far less than might be expected (see discussion in future technology section later in paper). Much of the schedule for Stoa is devoted to the initial buildup of seed, to multi-year testing, and to

Table 6-2. Breeding and Seed Increase History For Stoa Hard Red Spring Wheat.

Year	Season	Generation	Explanation of evaluation state
1973	Fall	Cross	ND527/Coteau sib//Era
1974	Spring	F_1	Grown in greenhouse
1974	Summer	F_2	Space-planted populations
1975	Summer	F_3	Head-row
1976	Summer	F_4	F_2-derived head-row
1977	Summer	F_5	1 row selected, F_4 derived line
1978	Summer	F_6	Preliminary evaluation
1979	Summer	F_7	Preliminary yield trial
1980	Summer	F_8	Elite yield trial
1981-83	Summer		ND HRS Variety trial (tested as ND582)
1982-83	Summer		HRS Uniform Regional Nursery
1983	Summer		Spring Wheat Quality Advisory Committee Test
1984			Named and released

Seed Increase (Concurrent)

1981-82	Purification head rows near Yuma, Arizona
1982	Increase at North Central Station, Minot, ND, 1 1/2 acres
1982-83	Winter increase near Yuma, Arizona
1983	Increased in North Dakota
1984	Released as a variety
1985	26,000 acres certified plus non-certified acres
1986	Estimated acreage, 1 1/2 to 2 million acres

increasing the varietal seed. This testing and seed increase must be done regardless of how a line was produced initially.

The main reason for the foregoing discussion was to establish the time perspective for wheat breeding research. The crosses for the wheat varieties of Year 2000 are being made now, in 1988, 12 years earlier.

Hybrid Wheat

Much progress has been made during the past 25 years to develop germplasm and techniques for commercial production of hybrid wheats. A hybrid advantage for grain yield and other traits similar to those found in corn, sorghum, rice, and other crops is the impetus for hybrid wheat research. Because the farmer must purchase hybrid seed each year, unlike varietal seed which he/she can grow from the previous year's seed, the successful development of hybrid wheats also would be the basis for a large commercial seed industry in the United States. Several commercial seed and agricultural chemical companies have hybrid wheat research efforts.

Two technologies are being used for hybrid wheat development: 1) genetic systems which use a cytoplasmic male-sterile female parent and a fertility restorer male parent for hybrid seed production and 2) chemical systems which use chemical hybridizing agents (CHAs) to treat and to sterilize the female parent for production of hybrid seed by cross-pollination with the male parent. Commercial hybrids have been produced and marketed using both types of systems.

Current hybrid wheat research has two goals: 1) to improve hybrid performance, and 2) to reduce the costs of producing hybrid seed commercially. The economic success of hybrid wheat will be determined by the hybrid breeder's and seed producer's success in accomplishing these goals.

In general, the quality standards and questions for hybrids are identical to those for conventional varieties. The end use quality of hybrids has tended to be intermediate between their two parents for most traits. Some quality control can be achieved in hybrids by choosing parents which have complementary quality traits.

Wheat hybrids must have a yield advantage to be economical; therefore, the breeder must be concerned about grain yield-protein percentage relationships in the wheat classes where high protein is desirable. Also, seed produced on a hybrid (F_1) plant differs from seed produced on a variety. The (F_2) seeds are segregating, each being genetically different from one another. In conventional varieties, all seed is genetically homozygous and is homogeneous. Although these effects have not been examined in detail, generally, the maternal F_1 plant which is of uniform genotype appears to have the predominant effect on endosperm quality and on kernel characteristics.

A hybrid would be grown only on as much acreage as hybrid seed could be produced each year and would not be grown if the seed company did not produce the hybrid. Consequently, the acreage of hybrids of specific quality could be controlled, a practice not easy or practical for self-pollinated conventional varieties.

The Concept of Genetic Gain

The most basic concept in plant breeding is genetic gain. The formula which measures genetic gain, though seldom formally calculated, is implicit in any breeder's planning and projections.

The simplest expression of the formula is

GENETIC GAIN = PHENOTYPIC VARIANCE x SELECTION DIFFERENTIAL x HERITABILITY

Where: phenotypic variance measures the variation of the population of plants or lines upon which selection is being done for the trait in question; for example, the frequency distribution ~~for~~ protein percentage in an F_2 population.

standardized selection differential is based upon the proportion or fraction of total lines selected and the statistical normalized curve. For example, the standardized selection differential when the 10 highest protein lines are selected from a population of 100 lines (10% selection) is 1.755, and

heritability measures the extent to which the phenotype reflects actual genotype, that is, how closely selected lines actually perform in subsequent generations compared to the generation in which they were selected. Heritability, therefore, also measures the degree of environmental influence on a trait. (A trait such as grain protein percentage, with a typical heritability of 0.7, is considered highly heritable and is much easier to select than grain yield, for instance, with a typical heritability of 0.25, which requires far more effort and testing to verify comparative performance.)

Breeders can manipulate each of the components of the formula to improve genetic gain, a topic which involves plant breeding theory beyond the scope of this paper. In practice, experienced breeders deal more or less intuitively with genetic gain and its components.

Wheat Genetics and Cytogenetics

In the last 15 years, biochemists and cytogeneticists studying the endosperm storage proteins of wheat have established a broad basic framework of knowledge for understanding the biology, biochemistry and genetics of these proteins. This knowledge has laid the foundations for critical studies of numerous wheat genetics problems including experiments to understand in detail the genetic variation for the glutenin and gliadin components of wheat gluten and how this genetic variation relates to functional wheat dough properties.

The following brief introductory description of wheat's basic genetic makeup should be helpful in understanding the methodology of wheat genetics and cytogenetics.

Wheat (*Triticum aestivum* L.) is a hexaploid (polyploid) with 21 pairs of chromosomes or a total of 42 chromosomes (2n=42). Wheat has three different diploid genomes termed AA, BB, and DD, each with seven pairs of chromosomes. The three original genome donors are from related diploid (2n=14) species. The three genomes, though genetically differentiated, have retained much of their ancestral similarity in terms of relative gene locations on comparable chromosomes and also for gene function.

(Durum wheat, the only class that is tetraploid, not hexaploid. *Triticum turgidum* var. *durum* L., has 14 pairs of chromosomes (2n=28) and the AA and BB genomes. Although wheat cytogenetic methods have been successfully developed for durum wheat, they will not be discussed here.)

Cytogeneticists have identified each of the 21 wheat chromosomes and have placed them into seven groups, each having the three corresponding (homoeologous) chromosomes of their diploid progenitors (Table 6-3).

The polyploid nature of bread wheat is the basis for a sophisticated system of cytogenetic methodology. With its three genomes, bread wheat, in essence, has three nearly complete sets of genetic instructions (genes). Consequently, it can tolerate the loss of a single chromosome (monosome) or chromosome arm (telosome) for each of the 21 chromosomes. It also tolerates several other alterations of chromosome number, both additions and reductions, from the normal 42 chromosomes. The general term for deviations of chromosome number from the standard set of 42 chromosomes is aneuploidy. Wheat cytogeneticists have developed sets of several kinds of aneuploid stocks which are used extensively in genetic studies of wheat.

Cytogeneticists can determine the chromosomal location of a gene by crossing a given wheat variety with a standard set of 21 monosomics, or with other aneuploid sets, and by studying the progeny from the 21 crosses. They correlate the presence or absence of the trait in question, a glutenin protein, for example, with the presence or absence of specific chromosome or chromosome arm.

Wheat Gluten

The distinctive properties of doughs made from wheat flours are a function of the quality and quantities of the protein component of the

Table 6-3. The Chromosomes of Bread Wheat.

Homoeologous group	Genome		
	A	B	D
1	1A	1B	1D
2	2A	2B	2B
3	3A	3B	3D
4	4A	4B	4D
5	5A	5B	5D
6	6A	6B	6D
7	7A	7B	7D

The six chromosomes that carry storage protein genes are underlined.

seed endosperm. Wheat gluten, one of the most intricate naturally occurring protein complexes, can be divided on the basis of solubility into two fractions, glutenins and gliadins, which have very different biophysical properties (Payne et al., 1984; Bietz, 1987).

Native glutenins consist of numerous polypeptides further associated as complex polymers. About 10% of the storage proteins in a typical wheat flour are high molecular weight (60-70KD) glutenins, and about 30 to 40% are low molecular weight (30-40KD) glutenins. Glutenins now are considered as the primary determinants of dough strength, imparting elasticity to bread dough (mixing requirements).

The remaining 50% of the flour storage proteins are gliadins, which occur as a complex mixture of single polypeptides. Gliadin is viscous and gives extensibility to dough.

Several techniques of protein analysis have made it possible to separate, to identify, and to characterize these very complex gluten proteins. The techniques include 1) several types of polyacrylamide or starch gel electrophoresis which separate individual proteins on the basis of their electrical charge or mass; 2) high performance liquid chromatography (HPLC), a more sophisticated means of separating proteins to provide both quantitative and qualitative data on single proteins; 3) immunochemical analysis; and 4) amino acid sequence analysis, the ultimate technique for comparing similar proteins and changes caused by mutation.

The Chromosomal Location of Storage Protein Genes

What has emerged from experiments designed to determine the genetic control of endosperm storage proteins, using protein separation and cytogenetic techniques, is a remarkably comprehensive analysis which accounts for the complexity of wheat gluten and for the several hundred polypeptides (among wheat varieties) of which it is composed.

Briefly, this analysis states that genes at nine complex gene loci, located on six different chromosomes, code for the endosperm storage proteins (Payne, 1984). The long arm of chromosomes 1A, 1B, and 1D each has a complex locus for high molecular weight glutenin subunits (genes designated Glu-A1, Glu-B1, and Glu-D1, respectively). The short arm of these three chromosomes each carry complex loci that contain structural genes encoding certain types of gliadin proteins and low molecular weight glutenins (genes designated GLI-A1, GLI-B1, and GLI-D1, respectively). The remaining three complex loci, located on the short arms of chromosomes 6A, 6B, and 6D, contain genes encoding other types of gliadin (genes designated GLI-A2, GLI-B2, and GLI-D2, respectively).

Each complex locus contains members of gene families which have arisen through gene duplication followed by mutation. Consequently, substantial capacity/opportunity for allelic variation within a single complex locus is possible. This capacity to code for protein variants is extended further because of the three sets of loci (on the A, B, and D genomes) for each of the three glutenin and gliadin gene types.

This gene system has the capacity to code for the several hundred different polypeptides and may be responsible for differences among varieties in protein quality as it affects dough handling and baking properties.

Current and future research on the glutenin and gliadin proteins has several goals: 1) to assess the qualitative genetic variation for seed storage proteins using gel electrophoretic or HPLC protein separation methods. (Ideally, several dozen varieties, even several hundred varieties, in each wheat class would be evaluated); 2) to assign alleles encoding specific glutenins or gliadins to a specific chromosome locus; 3) to determine which alleles (specific glutenins or gliadins) affect bread making or other processing characteristics most favorably; and 4) to evaluate the effects (both direct and indirect) of genes other than the nine complex loci on protein quality and on other traits important to overall quality.

Many years of intensive research will be required to achieve these goals. For example, as alleles coding for different glutenin proteins are found, their functional effect on mixing properties must be determined comparatively. Populations of lines which are segregating for alleles at the locus in question must be evaluated to determine which allele they have and also what their mixing properties are. The relative effects of the two alleles on mixing properties among many lines determine their relative classification as favorable or unfavorable. A large number of lines must be assessed because genes other than those being evaluated also can affect mixing properties.

The relative effects of specific alleles on protein quality also can be determined by developing isolines developed by backcrossing different genes into a common genotype. Few lines then are needed to evaluate the relative effect of the gene in question (and its associated protein) on functional quality properties.

This research should identify 1) which of the nine complex loci affect protein quality the most, 2) the relative effects of alleles within each of the nine loci on protein quality, and 3) the relative effects of combinations of genes on the different loci on protein quality. Furthermore, which proteins are considered favorable may vary among wheat classes and among end-product uses.

Distinctive proteins may be identified as genetic variation among endosperm proteins is evaluated. The wild relatives of wheat and older "land races" are probable sources of such proteins.

Eventually, this research could provide the cereal chemist and breeder with more definitive tests of protein quality, supplementing existing functional tests. Knowing the genotypes of parental lines for the glutenin and gliadin proteins would assist the breeder greatly in planning crosses between parents which have complementary favorable proteins. If enzyme linked immunosorbent assay (ELISA) or DNA-probes for specific favorable proteins or alleles could be made (discussed later), early generation testing would facilitate selection of desired progenies sooner. Knowledge about these genes and their effects also will be needed to direct research efforts to genetically engineer "quality" genes.

Future Technologies for Wheat Improvement

Advances in several technologies for genetic manipulation of plant cells and genes, collectively termed biotechnology, have generated much discussion about their application to important plant breeding problems.

Briefly, several of these technologies and their potential use to augment, replace, or extend the wheat breeding procedures will be discussed in the context of the three phases of wheat breeding discussed earlier in the paper: 1) introduction of variation for the traits of interest; 2) selection among the derived variants (experimental lines) for useful genotypes, and 3) the extensive evaluation of the selected experimental lines in different environments and years with the goal of identifying the best-performing lines for release as varieties.

Genetic Engineering

The new technology having the greatest potential for expanding the genetic variation available to plant breeders is genetic engineering.

Genetic engineering is the technology or group of technologies with which scientists can isolate genes from one organism, manipulate them in the laboratory, and then insert them stably into another organism (this stable insertion is known as transformation). These complex technologies are the focus of extensive, very active research efforts (see, for example, discussions by Fraley et al., 1986; Cocking et al., 1987; and Schell, 1987)

The capabilities of scientists using genetic engineering now are limited in wheat and most major crop plants. These limitations regarding wheat quality include: 1) insufficient knowledge of which genes affect quality; 2) great difficulty in isolating such genes; even if they are known; 3) inability to stably insert specific genes into the host genome; and 4) not knowing how to regulate the expression of inserted genes in the target tissue. While some of these limitations are likely to have technical solutions in the near future, others could remain as major barriers to using these techniques in wheat breeding for some time.

Once specific favorable alleles of the genes that code for glutenin or gliadin proteins are identified, a process which could require a great deal of research, the isolation of these genes could become fairly routine. Current research indicates that many of the wheat seed storage proteins actually are "families" of proteins (many similar but slightly different proteins) coded by "families" of genes (Metakovsky et al., 1987; Payne et al., 1984).

Genetic engineering also can isolate seed storage protein genes from other crops. The potential value of these proteins either to improve wheat quality or to impart additional processing attributes to wheat cannot be assessed until such genes actually are inserted into wheat and are expressed in the seed. Most of the changes in the protein composition of the flour probably may be detrimental.

At the time this report is written (December, 1987), there are no reports that cultivated wheats (*Triticum spp.*) have been transformed and a plant regenerated (Cocking and Davey, 1987). Genes have been inserted into the cells of a wild relative of wheat (*T. monococcum* L.), but no plant was regenerated because of inability to regenerate plants from single cells which requires an effective tissue culture system (described later). Although Schell (1987) has reported that DNA is taken up and is expressed transiently in wheat embryos, he has not determined if this DNA is transmitted to the offspring, e.g., is heritable.

A prudent estimate is that appropriate techniques to genetically engineer wheat will be developed within the next five years assuming adequate resources for the necessary experiments. How effective or efficient these systems will be is difficult to predict.

An example of technology which must be developed when wheat plants are transformed successfully is the regulation of the expression of genes for quality. The genes must be expressed in the seed but not in other tissues. Experience with other crops indicates that the regulatory sequences for wheat seed proteins will have many of the necessary characteristics for regulating the added new genes (Schell, 1987). Colot et al. (1987) have identified regulatory sequences required for tissue-specific expression of a low molecular weight glutenin gene. Genetic engineering allows the addition of relatively few genes, not a gene family. Because gene families for quality are expressed in the seed, the added genes may need to be strongly expressed for them to affect quality positively.

If detrimental proteins, for example, the secalin proteins of the 1B/1R rye translocation are operative, turning off these families of genes may be necessary, requiring techniques not now known. However, germplasm may be found using suitable analytical tools, either through natural variation or through chromosomal manipulation, which lacks the detrimental family of genes.

It must be restated, however, that until useful genes can be successfully identified, isolated, stably integrated into the wheat genome, and sexually transmitted to offspring, genetic engineering of wheat remains a promise and a goal rather than a useful tool.

If procedures that allow the routine genetic transformation of wheat should become available within five years, how long would the new technologies take to have a major effect on wheat quality?

Research to better understand wheat proteins and the specific genes that code for them, including methods to isolate these genes, will proceed concurrently with research on genetic transformation.

However, to fully manipulate gene regulation in seeds will take many years. Transformed plants must be grown to maturity to test seed for gene expression. Small-scale baking quality tests to determine if wheat quality has indeed been improved requires 300 g (0.7 lbs) of seed. Advanced hard wheat quality evaluations can require up to 550 kg (1200 lbs) of seed.

The selfed seed from one fertile transformed plant must be tested to determine in which progeny the inserted gene is homozygous (pure breeding). The selected homozygous progeny, grown under optimal conditions, could produce 1000 to 2000 grams of seed. Hence, one year after harvesting seed from a successfully transformed plant, seed would be available for the initial quality testing. Under more normal conditions, it may take two generations to produce enough seed for the critical, initial quality evaluations. For advanced quality testing, two and three years are required under optimal and normal conditions, respectively, to obtain sufficient seed for the tests.

Extensive field testing, conducted concurrently with the quality testing, would be needed to determine if the transformation event and the new gene(s) have any adverse effects on agronomic performance. The testing also must verify that the new gene was integrated stably into the genome, was transmitted normally to the progeny, and was expressed properly.

The first field tests of transformed plants (mainly tomato and tobacco) in the United States were allowed in 1987. Hence, there is little or no previous knowledge and experience on which to base speculations about the agronomic and quality performance of transformed wheat. Assuming the new transformed wheat has excellent quality and agronomic performance, another one to two years of seed increase would be needed before sufficient foundation seed could be sold to certified growers who, in turn, must grow the seed for one year before they can sell certified seed to the wheat grower. The first genetically engineered seed will enter the commercial market after the following growing season (an additional year) when the wheat grower harvests his crop. Commercial acceptance and use of the new, genetically transformed variety then can be determined.

Consequently, at least seven years will be required, under unusually favorable circumstances, for a seed of a genetically transformed variety to reach the commercial market--plus possibly another five years to develop the transformation technology. Although this seems a long time, it is slightly shorter than the normal timeframe of 12-15 years necessary to develop a wheat variety.

In reality, there still are too many unknowns about the genetic transformation of wheat to predict future timetables confidently. While the current intense research focus on genetic transformation of plants should lead to relatively rapid progress, the problems of implementing these techniques in an applied breeding program also may not be fully comprehended yet.

ELISA and DNA-Probe Screening Assays

There are several other new technologies that should help the plant breeder to select more efficiently among wheat quality variants in breeding populations. After proteins and genes that enhance or lessen wheat quality have been identified, rapid assays using antibodies or nucleic acids can be used to identify lines having these genes.

An example of this technology is the enzyme-linked immunosorbent assay (ELISA), which uses antibodies to identify proteins rapidly. ELISA technology employs a "capture" antibody which is attached to a solid surface and which specifically binds to a single protein from a complex protein mixture. This protein-antibody complex is incubated with an enzyme-coupled antibody which recognizes and binds to the protein. In the presence of a colorless substrate, the enzyme will convert the substrate to a colored product which can be measured spectrophotometrically. The presence of color, therefore, identifies the presence of the (specific) protein that bound both to the capture antibody and to the enzyme-coupled antibody (Nakamura et al., 1986).

ELISA tests are used routinely to identify seed storage proteins and proteins of plant pathogens (as a diagnostic test for diseased plants). Using ELISA techniques to identify specific seed quality proteins is difficult because these proteins occur as families of similar proteins. Polyclonal antibodies probably will cross react with some gliadins and glutenins. Only monoclonal antibodies, because of their specificity, will have any chance of success, and their production and screening is labor intensive. Isolating specific proteins and obtaining precise antibodies can be very difficult. However, once the technique is optimized, selection to save lines with favorable quality proteins and to discard lines with unfavorable proteins will be straightforward.

The ELISA technology is not used widely yet because of lack of understanding about which genes affect quality. However, basic research to study these proteins, using ELISA techniques and developing antibodies, should, if successful, make ELISA technology available to breeding programs.

A nucleic acid technique which rapidly identifies lines having a rye segment with useful agronomic genes (the 1B/1R wheat-rye chromosome translocation) has been developed (Hutchinson et al., 1985). In this technique, DNA from the plant is denatured (changed from its normal doubled-stranded form to a single-stranded form) and is hybridized (allowed to reform double-stranded DNA) with a radioactive DNA probe (a small segment of DNA) specific for the rye chromosome segment. An assay for radioactivity then indicates whether the rye chromosome segment is present in the plant. In lines with the 1B/1R translocation, the wheat glutenin-gliadin genes on the short arm of chromosome 1B, important to maintaining gluten quality, have been replaced by rye genes. The DNA probe, therefore, is useful either to select for the 1B/1R translocation (for useful agronomic and disease resistance genes) or to select against it (for adverse quality effects).

Biochemical Selection and Doubled Haploid Breeding

Two new technologies which also might be applied to genetic improvement of quality are biochemical selection at the cellular level and doubled haploid breeding. Both techniques involve tissue culture, the ability to form unorganized tissue (called callus) from organized plant tissue such as immature embryos and anthers on a culture medium, and then to reform organized tissue which can be induced to regenerate into plants.

With biochemical selection, the unorganized tissues are challenged (exposed) to a chemical that inhibits normal growth. Cells that have undergone mutations or other genetic changes that make them resistant to the effects of the chemical will grow normally and can be identified (Jacobs et al., 1986). The power of this technique is that approximately 2.25 million cells can be grown in 30 ml (about one fluid ounce) of medium. Each of these cells potentially can regenerate into a plant. By comparison, an acre of wheat has from one to two million plants, depending on seeding rate. For selection purposes, an ounce of cells capable of regenerating into plants is the numerical equivalent of one or two acres of wheat in a wheat nursery. It cannot be considered the functional equivalent, however.

While selecting directly in tissue culture to improve quality traits that are expressed in the seed may be difficult, selection may be possible for overproduction of essential amino acids that limit nutritional quality (Hibberd et al., 1980). Little variation for nutritional quality exists in wheat germplasm, and unconventional selection techniques may become an important objective for improving nutritional quality, lysine content, for example (Johnson et al., 1985).

Wheat culture techniques to produce large quantities of regenerable cells routinely have not been refined. Few plant traits, including quality traits, can be selected at the cellular level. New biochemical strategies to improve nutritional quality probably will not be developed until tissue culture systems are developed fully, probably within the next five years. Again, as with genetic transformation technology, seven years of testing and seed increase still will be necessary before the improved line would enter seed trade channels.

Doubled haploid breeding could shorten the time needed to develop inbred lines of wheat which normally are derived by generational advance following crossing. Most commercial wheat varieties are relatively homogeneous inbred lines as are the two parents of hybrid wheats.

The key to doubled haploid breeding is the ability to form haploid wheat tissue and/or plants whose chromosome number can be doubled using colchicine (Baenziger et al., 1984). Since common wheat is a hexaploid with 42 chromosomes, a "haploid" wheat plant is actually polyhaploid (triploid with half the chromosome number of the hexaploid or 21 chromosomes). Haploid tissues can be found in gametic tissues. Both the microspore (which will develop into the pollen grains) and the megaspore (which will develop into the ovules) are naturally polyhaploid. Hence, culture of polyhaploid tissues, such as anthers containing microspores, ovaries, or ovules, can give rise to polyhaploid plants whose chromosome number can be doubled to form hexaploid wheat plants (Keller et al., 1987).

The value of this technique is that when the chromosome number of the polyhaploid is doubled, each of its genes is copied identically. The doubled haploid line is completely homozygous (having identical genes at a locus) and inbred. In wheat, the process of forming polyhaploid callus, regenerating plants, and doubling the chromosome number can be completed in one year. In winter wheats, developing equivalent inbred lines by conventional inbreeding would take four or more years. In spring wheat, the time advantage is less, because inbred lines can be developed in two or more years by growing two or more generations per year.

Using a rapid inbreeding procedure not only saves time, but quality analyses on inbred lines are more reliable than those on segregating lines. Some of the difficulties in evaluating early generation lines are that they are heterozygous (having different alleles at a locus) and segregating (different plants have different genotypes). Inbred lines selected from such segregating (incompletely inbred) lines may not have the same quality traits initially selected for. Most quality tests involve milling (destroying) the seed. The seed saved for further breeding must be representative of the sample evaluated. This sampling is not a problem with completely inbred lines which are true breeding.

The major limitation with doubled haploid breeding in wheat is that an efficient system for producing doubled haploids has not been developed. However, using a relatively inefficient anther culture system, French researchers who developed the wheat variety 'Florin' which was released in 1987 believe they had saved four years by reducing time needed for inbreeding. Predicting when an efficient system for anther, microspore, ovary, or ovule culture will be developed is difficult because this area of research has generally received less attention than other tissue culture research.

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FUTURE OUTLOOK.

The nature of "future outlook" is quite clearly evident from the discussion in chapters 1 through 4 on Wheat Classes. However, the "die is cast" regarding the nature of potential new wheat varieties for the next 10 years approximately, because wheat breeders are making "today" the "crosses" or hybridizations of selected parents from which segregating progenies will come and potential new varieties selected in 1997 based on present perceptions of end use products. The discussions in Chapters 1 through 4 demonstrate clearly that cereal chemists of the State Agricultural Experiment Stations, or ARS, USDA, in some cases, have been communicating the needs of the milling and baking industry, or equivalent for other Classes, for 70 or more years, and the wheat breeders have responded, although variably, to breed wheats having as many as possible of the wheat kernel quality characters needed for the end use products. However, the wheat breeders also must produce varieties having satisfactory grain yield, resistance or immunity to many plant diseases, and other essential agronomic characteristics or the farmer will not grow the variety. For example, adequate grain yield of all Classes is needed, varieties highly resistant or immune to wheat stem rust are needed in the spring wheat region, and each wheat class needs certain minimal agronomic and end use characteristics to be a successful variety.

True wheat hybrids now are being produced by seed companies and grown by farmers on a very small percentage of the total wheat acres. The use of wheat hybrids probably will increase slowly in the next 10 years depending on whether their grain yield is sufficiently superior to the best conventional varieties to compensate for increased seed cost, and their end use quality is satisfactory. Very little information is available about kernel morphology or the end use quality of seed produced on the F_1 plants of hybrids which becomes the commercial milling wheat in commerce.

A problem of changing morphology of the traditional wheat kernel is developing especially in the red wheat classes. Wheat classes are classified into one Class or another based primarily on kernel morphology by licensed grain inspectors and the Federal Grain Inspection Service. Problems have developed recently in kernel classification especially of the red wheats based on traditional kernel morphology. Although wheat breeders make relatively few interclass crosses, some confusion in classification has resulted from wheat breeders making interclass crosses, primarily between HRWW and SRWW or HRWW and HRSW, to achieve genetic diversity for one or more agronomic characteristics such as disease resistance or to increase the protein quantity and quality of HRWW by crossing with HRSW, or for various other reasons. Or, while wheat breeders make relatively few direct interclass crosses of specific varieties, practically all wheat germplasm now used as parents in crosses have diverse parentage, e.g., the parents of the cross which led to the HRSW variety 'Stoa' had at least 36 different sources of wheat germplasm in the "grandparent" lines.

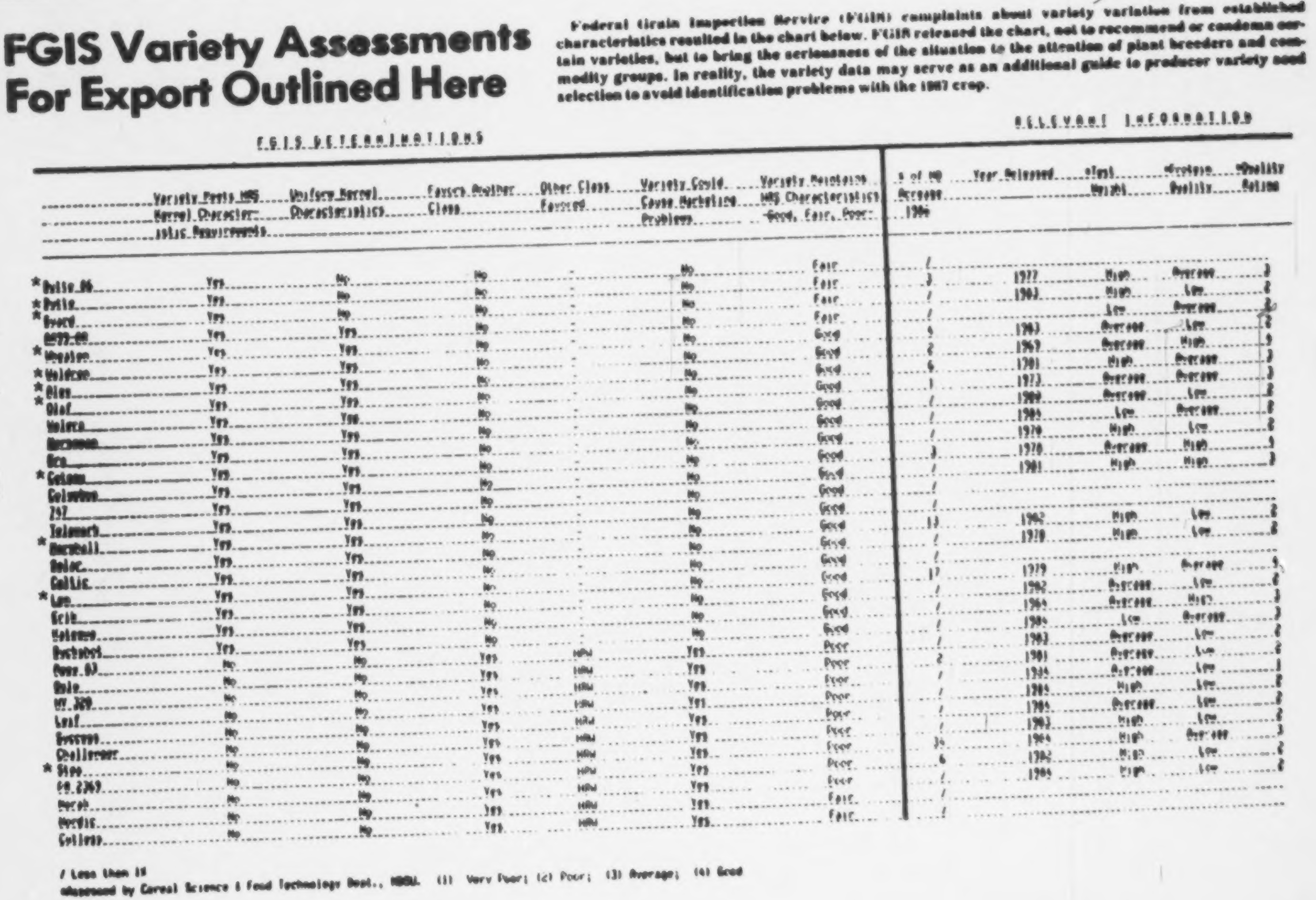
The variety 'ARKAN', for example, developed in Kansas as a HRWW had a kernel morphology which confused it with SRWW as grown in some environments and in marketing especially as the borders of the two

Class regions are adjacent and merge together. Kernel morphology of certain varieties of HRWW and HRSW also have varied from the traditional. The wheat kernels produced on F_1 plants of true wheat hybrids usually will have kernel morphology intermediate between the two parents, thus presenting no problem or a variable problem in kernel classification.

'STOA' hard red spring wheat is an example of a popular, very productive variety with good end use quality described by FGIS as having kernel morphology problems, see Table 7-1 (Maier, 1987). However, as grown in the field and graded by licensed inspectors in North Dakota and Minnesota, and having FGIS "supervision" or oversight, 29 samples of Stoa submitted to licensed inspectors in North Dakota and Minnesota in late 1986 all graded Dark Northern Spring or Northern Spring (2 subclasses of HRSW) (Fisher, 1986). Further, 5 samples of Certified Stoa and 4 samples of Certified Stoa and Certified Len mixed 50/50 were all graded by licensed inspectors Dark Northern Spring with no other class content along with a single sample of 'Roughrider' hard red winter wheat which was graded correctly as Hard Red Winter Wheat. Further, the Canadian Wheat Board classified Stoa as a typical HRSW for kernel type. In 1986, as shown in Table 7-1, 53% of the HRSW grown in North Dakota had typical HRSW kernel type or 87% if the 34% of Stoa (Maier, 1987) grown is added as typical kernel type indicating that a traditional kernel type problem has not reached extremely serious proportions in the principal hard red spring wheat production region.

Solutions to such problems appear to be (1) changing the wheat classing system to eliminate the need for Class identification based on kernel morphology, especially in red wheats; (2) wheat breeders should

Table 7-1. Classification by the Board of Appeals and Review, Federal Grain Inspection Service, Kansas City, of Varieties of Hard Red Spring Wheat for Kernel Morhpology.



FGIS Variety Assessments For Export Outlined Here

Federal Grain Inspection Service (FGIS) complaints about variety variation from established characteristics resulted in the chart below. FGIS released the chart, not to recommend or condemn certain varieties, but to bring the seriousness of the situation to the attention of plant breeders and commodity groups. In reality, the variety data may serve as an additional guide to producer variety seed selection to avoid identification problems with the 1987 crop.

	F G I S D E T E R M I N A T I O N S						R E L E V A N T I N F O R M A T I O N				
	Variety Meets HRS Kernel Characteristic Requirements	Uniform Kernel Characteristics	Favors Another Class	Other Class Favored	Variety Could Cause Marketing Problems	Variety Maintains HRS Characteristics Good, Fair, Poor	% of ND Acreage 1986	Year Released	aTest Weight	aProtein Quality	aQuality Rating
*Butte 86	Yes	No	No	-	No	Fair	/				
*Butte	Yes	No	No	-	No	Fair	3	1977	High	Average	3
*Guard	Yes	No	No	-	No	Fair	/	1983	High	Low	2
2375	Yes	Yes	No	-	No	Fair	/	—	Low	Average	2
*Wheaton	Yes	Yes	No	-	No	Good	5	1983	Average	Low	2
*Waldron	Yes	Yes	No	-	No	Good	2	1969	Average	High	3
*Olex	Yes	Yes	No	-	No	Good	6	1981	High	Average	3
*Olaf	Yes	Yes	No	-	No	Good	1	1973	Average	Average	3
Walera	Yes	Yes	No	-	No	Good	/	1980	Average	Low	2
Norseman	Yes	Yes	No	-	No	Good	/	1985	Low	Average	2
Era	Yes	Yes	No	-	No	Good	/	1970	High	Low	2
*Coteau	Yes	Yes	No	-	No	Good	3	1978	Average	High	3
Columbus	Yes	Yes	No	-	No	Good	/	1981	High	High	3
737	Yes	Yes	No	-	No	Good	/				
Telemark	Yes	Yes	No	-	No	Good	/				
*Marshall	Yes	Yes	No	-	No	Good	13	1982	High	Low	2
Bolac	Yes	Yes	No	-	No	Good	/	1979	High	Low	2
Celtic	Yes	Yes	No	-	No	Good	/				
*Len	Yes	Yes	No	-	No	Good	17	1979	High	Average	3
Erik	Yes	Yes	No	-	No	Good	/	1982	Average	Low	2
Solomon	Yes	Yes	No	-	No	Good	/	1964	Average	High	3
Buckshot	Yes	Yes	No	-	No	Good	/	1986	Low	Average	3
Powr 83	No	No	Yes	HRW	Yes	Poor	/	1983	Average	Low	2
Dala	No	No	Yes	HRW	Yes	Poor	2	1981	Average	Low	2
MT 309	No	No	Yes	HRW	Yes	Poor	/	1985	Average	Low	1
Leaf	No	No	Yes	HRW	Yes	Poor	/	1985	High	Low	2
Success	No	No	Yes	HRW	Yes	Poor	/	1985	Average	Low	2
Challenger	No	No	Yes	HRW	Yes	Poor	/	1983	High	Low	2
*Stoa	No	No	Yes	HRW	Yes	Poor	34	1984	High	Average	3
ND 2369	No	No	Yes	HRW	Yes	Poor	6	1982	High	Low	2
Marah	No	No	Yes	HRW	Yes	Poor	/	1985	High	Low	2
Nordic	No	No	Yes	HRW	Yes	Fair	/				
Cutless	No	No	Yes	HRW	Yes	Fair	/				

/ Less than 1%

aAssessed by Cereal Science & Food Technology Dept., NDSU. (1) Very Poor; (2) Poor; (3) Average; (4) Good

Varieties with asterisk composed 87% of the North Dakota acreage in 1986 crop year.

develop and release only varieties with traditional Class kernel morphology; or (3) a system of a "black box" must be developed to allow licensed grain inspectors and FGIS to distinguish Class percentage of small representative samples of wheat grain either pure for Class or having a mixture of Classes. The proposal has been, and research is underway, to distinguish among red wheat classes with an instrument measuring kernel hardness and protein percentage for Class identification. Such a device would seem less likely successful to distinguish HRWW from HRSW easily and accurately or to be precise at required class tolerance levels, or to be used easily, quickly and accurately at all levels of the wheat marketing system from country elevator to terminal markets, wheat export points, or at other destinations. The problem remains unsolved now but will require resolution in the near future to satisfy procedures in the regulatory FGIS system and to provide accurate identification of Class content in the domestic and export marketing system. A temporary solution by FGIS has been to provide a procedure for Class identification based on intended Class of each variety and geographic area of production. Further, a "Wheat Classing Working Group" (Martinez, 1988) appointed by Dr. K. A. Gilles, former Administrator of FGIS, is working to develop (1) tests to evaluate relative kernel harndess of small samples of wheat, (2) means to evaluate and identify single wheat kernels for hardness and spring vs. winter among red wheats, and (3) other means to help resolve the wheat classing problems in the marketplace.

An additional Class identification and isolation marketing problem would appear to be the development and production of hard white winter wheat (not the Hard White subclass of the PNW) in California, Kansas, and Montana to process and use as equivalent to a white pan bread flour. The problem will be to distinguish a hard white for pan bread from the hard and soft whites of the Pacific Northwest for the cracker and cake flour uses, and possibly from bleached and/or soft wheats of the SRWW and HRWW Classes. A hard white wheat variety, Klasic (spring habit planted in winter) already is produced and released by Northrup King in 1981 and in production in California, with 50,000 to 60,000 tons production expected in 1988. A winterhardy hard white winter wheat is seeded on 1000 acres in Kansas in 1987-88 for possible rapid expansion depending on agronomic performance and marketing opportunities. Montana also has a Hard White Wheat suitable for pan bread production in initial increase and trial marketing stages (Roberts, 1988). The variety Klasic is graded as Hard White in California by FGIS--evaluation to date shows Klasic to have excellent flour extraction and end use quality suitable to make white pan bread, i.e., "family flour", more or less. This type of hard white wheat is intended, as being evaluated in California, Kansas and Montana, for some domestic use and to compete with Australian hard whites in export markets. Present information indicates the white winter grown in Kansas and Montana may lack vitreous kernel percentage for Hard White.

Signals on wheat grain quality needs have come in the past from the Northwest Crop Improvement Association, 1952-59 (Smith, 1988), the Crop Quality Council, 1960-83 (Goodfellow, 1988), the Spring Wheat Quality Advisory Council, 1983-88, formerly CQC (Teigen, 1988), the former Hard Red Wheat Quality Council, now Hard Wheat Council (Roberts, 1988), and from the many components of wheat research and processing composing these groups.

Signals on wheat grain quality needs will continue to come from the processing industry and the consumer in the future, perhaps in increasing numbers and complexity, and the needs will be interpreted by the cereal chemist to the plant breeder in the "wheat breeding team" at the public institutions and in private seed companies. The wheat breeders will attempt to produce varieties having all the agronomic and quality characteristics that are possible to combine in the complex genetic procedure to be accomplished. The consumer, processing industry, and the "institutional influences" of all kinds should understand that some combinations of agronomic characteristics and wheat grain quality are extremely difficult or biologically impossible to achieve due to unfavorable genetic linkages, unavailability of the character in the wheat germplasm, the lack of sufficient genetic variability in the germplasm, extremely low heritability of the character, or other known or unknown reasons.

The use of techniques or tools of molecular biology or genetics may allow or accelerate genetic expressions or functions now very difficult or highly unlikely to achieve. However, the production and incorporation of useful characters from molecular biology are expected to be much slower in higher plants such as wheat than in such organisms as bacteria and fungi. Further, the incorporation of a new character in wheat obtained from any source into a commercial variety adapted for farm production still will require 8 to 15 years depending on relative heritability and other obstacles.

More sophisticated instruments and procedures and of how certain processes cause certain end results may allow faster progress in wheat breeding, and certainly a better understanding of biological processes involved.

Wheat varieties having characteristics suitable for modified or new uses may be developed to be produced in the geographic areas where wheat is now known to be well adapted. For example, an 18% protein hard red spring wheat may have special uses for frozen doughs or a high protein breakfast cereal. Certain wheats may be more useful as feed for livestock. A hard white wheat suitable for pan bread production is now grown in California, one is being evaluated in Kansas, and Montana has a project to develop a hard white wheat. Unfortunately, many new or different uses for one crop merely detract or subtract from a market now filled by another crop, that is, one carbohydrate food grain often is highly substitutable for another, for potato, cassava or other plant sources of carbohydrates. No unique, really new, large volume use for wheat or wheat products is known now, or known to be in a developmental stage. Further, little evidence exists that the marketplace will pay higher prices or a premium for a wheat having unusual characteristics suitable for producing unique or new products.

Farm programs of the Federal Congress will continue to influence directly or indirectly wheat breeding objectives of public and private wheat breeders because (1) the program tends to reward high grain yield records, and (2) "wheat is wheat" in the farm program with no recognition of variable end use quality as a premium/discount provision. This situation tends to "send a signal" to farmers and wheat improvement teams that high grain yield should take precedence over all other characters in the release decision for new varieties. Wheat breeders are now making the crosses from which the new varieties of 1997 to 2000 will come but the nature of the "farm program", if any

10 years hence, probably is the least predictable "signal" of all regarding the nature of new varieties needed in 1997 to 2000.

The funding of public and private wheat research in the future concerns wheat breeders and research administrators. Some State Agricultural Experiment Stations report (Lechtenberg, 1987) that state and federal funds for wheat breeding have decreased from 75% to 35% of total funding in the last 5 years. Other states have had slight decreases in the percentage of state and federal funds in the total funding of wheat research. Grant or gift funds from commodity organizations, funds from commodity "check-offs", funds from federal competitive or noncompetitive grants, royalties on sale of seed of varieties, and funds from whatever other sources available have replaced part of the lost state and federal funds if the wheat research project was retained. Some public Agricultural Experiment Stations and private seed companies probably have taken funds from applied wheat breeding projects and redirected such funds to the new biotechnology or other basic research. Often, funds from competitive or noncompetitive grants have different research objectives than to improve the agronomic and end use characteristics of wheat, thus reducing the research which will lead to improved varieties for domestic and export uses. Funds given by private industry to public programs have compromised the latter, and add to the public patent dilemma of plant genes or germplasm which may tie up genes and germplasm for 17 years.

The outlook would appear to be that the real dollar inputs into wheat breeding issues related to wheat grain quality from whatever and all sources has been decreasing in the last 10 years, and will continue to decrease unless funding sources are convinced that improved and maintained funding of such research is essential to maintain it at a level needed to produce the type of wheat varieties apparently desired to produce grain for domestic processing and that desired by our foreign customers.

Again, relating to subsidized export programs as P.L. 480 and the Export Enhancement Program, probably considerable variability in the end use quality of wheat exported in these programs had little, if any, influence on the volume exported (Milling and Baking News story, Dec. 15, 1987) or satisfaction of the customer, while the customer of course desires the best wheat quality and least nonmillable materials obtainable under the programs.

The environment of much of the Great Plains, the Pacific Northwest, and other areas of the United States is suitable to grow wheat of several classes and farmers like to grow wheat and are equipped to do so. Wheat production is compatible to "double-cropping" in much of the SRW region. Wheat will be the principal crop of much of this area on into the Prairie Provinces of Canada for a long, long time. Further, per capita use of "bread and bakery products" in the United States is increasing (Milling and Baking News stories, Oct. 28 and Dec. 8, 1987) slowly and probably will continue to do so, hence our domestic consumption of wheat should rise slowly in future years. A recent report in "Wheat Facts," an insert in The Wheat Grower (Anonymous, 1987), indicates that domestic consumption of wheat and wheat products in the United States has increased from 517,000,000 bushels in 1970 to an estimated 750,000,000 bushels in 1987.

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CHAPTER 8. SUMMARY AND IMPLICATIONS

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SUMMARY AND IMPLICATIONS

Wheat grain or kernel quality is discussed in this report for the Market Classes of wheat, Hard Red Winter, Hard Red Spring, Durum, and Soft Red Winter and White together by experienced, productive wheat breeders and cereal chemists conducting research on each Class. Each Class is discussed in Chapters 1, 2, 3 and 4, respectively.

The reader of this report is informed and should understand that grain or kernel quality of a class for the end use products of that class are distinct from and not directly or indirectly influenced by non-wheat material such as "foreign material or dockage" (composed of other grains, weed seeds, "chaff," dust, insect parts, etc.) in a parcel or lot of wheat for domestic or export use. Only Contrasting Classes or Wheat of Other Classes in the wheat grading system of the Federal Grain Inspection Service, USDA, (Miller, 1987) may influence indirectly the end use of the principal class in a wheat lot or parcel. The component Contrasting Class definition and use in wheat grading implies and is based on a wheat having a different end use than the principal wheat class of the parcel. The component, Wheats of Other Classes, is a total for other class content, thus WOC includes any contrasting classes present, or a class(es) with a similar or slightly different end use than that of the principal class of the wheat lot or parcel.

The term often used by foreign buyers, "nonmillable materials" in a parcel of wheat also is independent of or not related to the inherent grain quality of the principal class other than nonmillable materials may contain shrunken and broken kernels of the principal class, and related to the principal class if the variety(ies) involved may have a variable tendency for breaking or cracking at harvest or in mechanical handling.

A problem of changing morphology of the traditional wheat kernel is developing especially in the red wheat classes. Wheat breeders contend that they make very few direct crosses among named varieties of different classes but practically all parents now used in crosses have very diverse parentage possibly including another class or wild wheat among the many "grandparents." Thus the traditional kernel morphology of wheats may change as genetic traits from these other sources are incorporated to increase genetic diversity. These procedures have resulted in the release of some wheat varieties not having highly typical kernel morphology. True hybrid wheat also may produce kernels having kernel morphology intermediate between the two parents. The problem is primarily in the red wheat classes, SRWW, HRWW and HRSW. The resolution of the problem which must be feasible from the country elevator throughout the marketing system, will be (1) changing the classing system in red wheats, (2) a quick reversion to releasing only varieties having traditional kernel type, (3) development of a "black box" into which wheat kernels can be placed and information derived to quickly and accurately identify Classes or Class admixtures on the basis of kernel hardness, and NIR protein reading or a combination of information, or (4) development of some system not yet known.

Wheat breeders and cereal chemists have been conducting research on wheat grain quality as related to end use products for 50 to 80 years. The grain quality of hard red spring wheat varieties and prospective varieties was evaluated by cereal chemists at the North

Dakota Agricultural Experiment Station beginning in 1909 (Moran, 1985). The Soft Wheat Quality Laboratory at Wooster, Ohio, and the Hard Wheat Quality Laboratory at Manhattan, Kansas, were started in 1937 and 1938, resp., and the White Wheat Laboratory at Pullman, Washington, in 1946. Also, the Hard Red Spring and Durum Wheat Quality Laboratory of the ARS, USDA, was transferred in 1962 from Beltsville, Maryland, where it was started in 1915, to Fargo, North Dakota to work in cooperation with Cereal Technology and Chemistry, North Dakota State University, Fargo, North Dakota, and continues to evaluate end use quality of wheat submitted by breeders of the spring wheat region. The cereal chemists of these public wheat quality laboratories communicated with the wheat milling and baking industry to interpolate the end use quality needs in new wheat varieties, and the breeders attempted to include the needed quality characteristics along with the many needed agronomic characteristics into new varieties for good wheat performance on the farms of the United States. Some formal organizations, e.g., the Crop Quality Council composed of millers primarily (now Spring Wheat Quality Advisory Council) for hard red spring wheat, and predecessors of the present Hard Wheat Council for hard red winter wheat met annually, discussed end use quality of annual wheat crops, evaluated potential new wheat varieties, assisted in the winter increase of hard red spring and durum wheats in case of Crop Quality Council, and otherwise communicated with the wheat breeding teams. Other "institutional influences" for several decades have been Wheat Commissions or Councils, Crop Improvement Associations, National Association of Wheat Growers, foreign "trade teams" as they interpret needs of international buyers, U.S. Wheat Associates, administrators of wheat breeding programs, and farmers.

The major breeding objectives for wheat end use quality and essential agronomic characteristics are described in the Class Chapters 1 to 4, inclusive, and are summarized in Table 8-1 by Market Classes. The breeders and cereal chemists consider and evaluate at least 20 major and minor characters in detail including those listed in Table 8-1. The breeder must combine all of these characters in one potential wheat variety, each character being at an acceptable performance or use level and many characters at the maximum potential desirable level, e.g., near immunity or very great tolerance of wheat stem rust by hard red spring and durum wheat varieties.

Dozens or nearly 100 varieties in some classes of new superior wheat varieties have been released in the last 10 years. These varieties are listed by name, date of release and releasing agency in the Class Chapters. Most or all of these released varieties were evaluated for and met agronomic and end use standards as evaluated by official public or private variety release committees prior to release. While every released variety may not be ideal for one or more of the many agronomic and end use quality characteristics, those agencies evaluating the total worth of a prospective variety for release have considered the variety worthy of release, of production by farmers, and for processing by the wheat industry, both domestic and foreign. The monitors of suitable end use for the various classes are the public and private quality laboratories mentioned earlier, and the milling and processing industry.

The implications are that the inherent grain quality of the predominant wheat class in a parcel or lot of wheat in the marketplace

Table 8-1. Grain Quality and Agronomic Characters that Breeders Incorporate into the Five Market Classes Related to End Use and Field Production Performance.

Class and End Use	Characters	
	End Use Quality	Agronomic
Hard Red Winter Wheat for white pan bread	Wheat and flour protein; dough characteristics and mixing requirements; test weight and kernel characteristics; bake absorption; loaf and crumb characteristics; flour extraction and milling characteristics	Grain yield; winter hardiness; harvestability re straw strength, height, shattering; grain test weight, kernel hardness and vitreousness; disease and insect resistance; resistance or tolerance to environmental stress especially at flowering and grain filling
Hard Red Spring Wheat for white pan bread, blending with weaker flour, and hearth and specialty breads	Wheat and flour protein; dough characteristics; mixing requirements; test weight and kernel characteristics; bake absorption; loaf and crumb characteristics; flour extraction and milling characteristics; performance as hearth breads or for blending or specialty breads based on strong gluten and high protein	Grain yield; disease resistance especially to wheat stem rust; harvestability re maturity, straw strength, height, shattering; desired test weight, kernel morphology, hardness, vitreousness; resistance or tolerance to environmental stress, i.e., yield stability; suitable to swathing or straight combining; grain dormancy or resistance to pre- and postharvest sprouting
Durum Wheat for pasta production, couscous, etc.	Semolina and flour yield as milled; wheat and semolina protein; dough mixing characteristics; strong gluten; pasta processing; pasta cooking performance re firmness, elasticity (al dente); desired yellow color, kernel to cooked pasta	Grain yield; disease resistance especially to wheat stem rust; harvestability re maturity, straw strength, height, shattering; desired kernel morphology, hardness, size, vitreousness; resistance or tolerance to environmental stress, i.e., yield stability; suitable to swathing or straight combining; grain dormancy or resistance to pre- and postharvest sprouting
Soft Red Winter and White Wheat for yeast or chemical, leavened or not leavened, cakes, cookies, crackers, noodles; breakfast cereals;	Low to medium wheat and flour protein percentage; high milling yield of fine textured flour without excessive starch damage; high "first break" flour yield; low water absorption; low amylase content or sprout damage; soft, easily milled kernel	Grain yield at relatively low to medium grain protein percentage; winter hardiness; disease and insect resistance; harvestability; early maturity re double cropping; test weight and kernel weight; straw characteristics and good harvestability

has been bred to meet the perceived end use quality standards for processing to one or more end products and the grain quality of the predominant class is independent of any non-wheat component of the parcel except indirectly as discussed for Contrasting Classes and Wheats of Other Classes earlier.

The research to improve wheat grain quality for current uses continues in public and private "laboratories." Some research considers other uses for present wheat or changing wheat genetically by present procedures, or changing wheat with the tools of the new biotechnology so wheat can be used for new products. (However, the reader should be cognizant that "new" food products often only displace another food product from another crop resulting in no net gain in the use of farm products. For example, wheat, bulgur from wheat, rice, potatoes and pasta are competing carbohydrate foods for human use.) Present breeding procedures or wheat improvement with new biotechnology requires 8 to 15 years to produce a new variety and no new techniques are available to shorten the developmental period. (See the Chapter 6 discussion.) The "new varieties" for 10 years hence, i.e., 1997 to 2000 are now "on the drawing board" as wheat breeders are choosing parents and making hybrids to meet the perceived characteristics for end use products at the end of the 20th century. No perceived great changes appear to be desired by the domestic or foreign wheat processing industry for end use products, so wheat varieties of 1998-2000 will be very similar to those of 1988, and they will have good agronomic and end use qualities.

Procedures for release of wheat varieties by both public and private agencies have been described. The breeding teams, the variety release evaluation committees, and the administration or management of all agencies carefully consider the agronomic and end use product "worth" of each wheat line proposed for variety release. "Institutional influences" are considered carefully. The quality laboratories and the processing industry have their input and, in general, varieties are released that meet the needs of the total wheat industry from farmer to consumer.

The cereal chemists have described the known factors, primarily of "protein families" and starch components of the wheat endosperm, that influence performance of the flour or semolina raw material to produce the desired end product. The breeders have described that most of the physical, biochemical and functional quality characters are controlled by many genes, that is, quantitatively, and their specific influences are very complex and difficult to study genetically. The authors of the chapter on wheat breeding technology have described the complex genomic nature involving many chromosomes in wheat and the use of the established science of genetic engineering, and cytogenetics, in present wheat genetics. They also describe the new "tool" of genetic engineering (biotechnology or molecular genetics), its potential to change wheat, and that the time period to develop a new wheat variety will remain at about 8 to 10 or more years using any of these technologies.

The implications are that our wheat breeding teams have been using information on end use quality of the wheat grain, that this quality is good for the perceived needs of the wheat industry from farmer to consumer, and that the wheat breeding teams will continue to meet these perceived needs, although slowly because of the inherently slow procedure of changing the wheat plant via breeding even including the new biotechnology.

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CHAPTER 9. SUGGESTED CONCLUSIONS

CHAPTER 9

SUGGESTED CONCLUSIONS

1. The inherent wheat grain quality as milled and processed to various end uses is independent from and not related to any nonwheat components or contaminants such as foreign material, other grains, or dockage in a lot or parcel of wheat for domestic or export use. The relative percentage of Contrasting Classes in the principal Class of the wheat parcel may or could have some slight direct or indirect effect on the end use performance of the wheat parcel as dilution effect or influence on the end use intended for the principal Class.
2. Laboratories to evaluate end use quality of commercial wheat and of potential varieties from wheat breeders were established as early as 1909 in the spring wheat region, in 1915 for spring wheat by USDA, Beltsville, MD, and about 1937-38 for soft red winter, hard red winter and white classes. Cereal chemists performed the comparative evaluations of desired end use characteristics, milling, baking, pasta extrusion and other uses as interpolated from the milling and baking industry.
3. Wheat breeders of the wheat breeding teams, including the cereal chemists, incorporated the desired end use characteristics along with essential agronomic characteristics into new varieties within limits of heritability and potential for favorable combination of up to 40 or more characters possible.
4. Various organizations such as the Crop Quality Council in the spring wheat region (now Spring Wheat Quality Advisory Council), the Hard Wheat Council, the Soft Wheat Council and other

organizations have evaluated wheat experimentals for end use performance for many years and participated in forums with wheat breeders, cereal chemists, and others to communicate about wheat improvement for the farmer, the processor and the consumer.

5. The end use quality of wheat produced in the United States appears to approximate the needs of both the domestic and export markets because wheat processors have communicated no major faults other than lack of "cleanliness" to wheat breeding teams. Of course, none of the agronomic or end use quality characteristics probably is at the highest attainable level desired by any component of the wheat industry and wheat breeding teams continue to attempt to improve all characteristics.
6. Wheat breeders today in greenhouses of public and private agencies, are choosing parents and making crosses which will produce progenies from which will come the new varieties of 1998 to 2000. Wheat varieties 10 and 12 years hence will be very similar to today's varieties with improvement in one or more agronomic and end use quality characteristics while holding other characteristics as good as now or better.
7. The list of new varieties developed and released in the last 10 years as presented in each Class Chapter will indicate the great productivity of the wheat breeding teams and the large number of varieties from which the farmer may select to evaluate for best performance on his/her farm, and having the end use qualities desired by the wheat processing industry.
8. Wheat kernel morphology as used to identify market Classes in the market place has developed into a classification problem as wheat

breeders have made "wide crosses" to increase genetic diversity. The problem is not easily solved but a solution is needed and may be achieved in the next 5 to 10 years.

9. Public and private wheat breeders have the same goals to incorporate the best possible agronomic and end use characteristics in potential new varieties or hybrids. The tables of variety surveys show the relative proportion of public and private varieties grown on farms in certain states where results are available. Funds for the Statistical Reporting Service, USDA, should be made available to conduct annual variety surveys because the information is needed and used by many people and agencies. Varietal surveys at 5 year intervals are less useful because of rapid annual change of wheat varieties planted.

10. True wheat hybrids requiring the purchase of seed by commercial wheat farmers each year are available and used to a limited extent, mainly in hard red winter wheat. The development of wheat hybrids requires two separate breeding procedures, one to develop a unique male wheat plant and one to develop a unique female plant, and has been progressing for 25 years. However, extensive use of wheat hybrids on any significant percentage of the wheat acreage probably will not occur in the next few years, partially because the yield advantage for hybrids is not sufficient at the present cash prices for wheat. The testing and use of "chemical hybridizing agents" to produce one or thousands of male-sterile wheat plants appeared to have the potential to accelerate hybrid wheat production, but this procedure appears now to have been delayed indefinitely for commercial production of hybrid wheat

seed on a large scale.

11. The new biotechnology may allow the "creation" of characteristics in wheat not possible earlier, or tried sufficiently using cytogenetics for example, but once a new character is created, its incorporation into an adapted wheat experimental line having the desired agronomic and end use characteristics still will require 8 to 10 years, the same time required to develop new varieties by present procedures.

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Background Paper No. 2

Soybean Breeding and Seed Quality

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U.S. Congress

This background paper was prepared for the assessment "Enhancing the Quality of U.S. Grain for International Trade." The views expressed are those of the author(s) and not necessarily those of OTA.

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SOYBEAN BREEDING AND SEED QUALITY

BY JOE BURTON

CHAPTER 1

Quality Definition

Each sector of the soybean (Glycine max L. Merr.) industry, as a whole, defines seed quality in a different way. Those who produce soybean seed for planting define seed quality in terms of germination percentage and the incidence of seed bourne pathogens. Alternatively, for industries which process soybean seeds into a variety of products, soybean quality is defined in terms of seed composition and to some extent physical appearance. This paper deals with soybean quality in this latter context. My objectives are to discuss soybean quality in relation to the soybean processing industry and the soybean grain trade and to determine the extent to which soybean breeding has affected and will continue to affect soybean quality in this context.

Physical Seed Quality

Physical seed quality is associated with the outward visible appearance of the seed. This is contrasted with physiological quality which is related to cellular metabolism and seed viability. The two are interrelated because a change in one can affect the other (McDonald, 1985). For instance, a seed bourne disease organism can affect the color and integrity of the seedcoat. Currently, soybeans that farmers sell as grain to a local elevator are graded according to U.S. grain standards for soybeans. The grading factors are essentially measures of physical appearance. They include test weight, total damaged kernels, heat damaged kernels, foreign material and limits for splits and color (Hill, 1985). Soybeans with physical quality are yellow, intact seeds without visible damage or disease. Because these seeds will eventually be processed and not planted, their physiological condition is irrelevant unless it affects the outward appearance. A soybean seed lot is classified into four grades and also a "sample" grade for those beans which fall below grade 4. Number 1 grade beans have a minimum test weight of 56 lb/bu, 10% minimum split seeds, 2.2% damaged seeds, 1% foreign material and 1% colored seeds - Table 1-1 (Official Grain Standards of the U.S.).

Seed size is not a grading factor, however, large variation in size is undesirable for processings. The machines which remove the seedcoats (hulls) of the soybeans must be set for a particular seed size range. Seeds which fall below this range require special attention for dehulling (Cargill, Inc., personal communication). Also, as seeds get smaller the hull percentage of the seeds increases. A higher percentage of hulls which have low levels of protein and oil, reduces the value of the seeds.

Biological Quality

Diseases which result in visible seed damage and discoloration can also reduce soybean grain value. Some of these can occur prior to harvest and others develop during storage after harvest. The primary fungi associated with preharvest seed decay are *Phomopsis* sp., *Diaporthe phaseolorum* var. *sojae* (Dps), and *D. phaseolorum* var. *Caulivora* (Dpc) (Kmetz, et al., 1978). Infection of soybean pods by the organisms occurs throughout the reproductive period (Kmetz, et al., 1978), and movement from the pod to the seed may follow. After seed maturity, warm, high humidity field environments with frequent rainfall can accelerate fungal growth and lead to seed decay (Kmetz, et al., 1979, Shortt, et al., 1981, Spilker, et al., 1981, Tekrony, et al., 1983). In such an instance, the seeds are visibly moldy at harvest. *Cerocospora kikuchii* is another fungal organism which infects seeds during their development. This infection causes a purple coloring of the seedcoat, a condition known as "purple seed stain". Rate of infection is higher in early reproductive stages and development of this disease may be enhanced by a warm humid environment during inoculations and initial infection (Roy and Abney, 1976). U.S. grading standards permit no more than 5% purple stained seeds. Thus, this disease can reduce the crop value for the farmer. Purple stain is not a problem for seed processors, because the color disappears with the normal heat treatment of processing (Athow, 1987).

The virus diseases soybean mosaic (smv) and soybean stunt (ssv) also cause discoloration of the seeds. This results from the movement of pigment from the hilum into the seedcoat. While this discoloration per se is usually not associated with low grain quality, smv alone or in combination with bean pod mottle virus (BPMV) can cause a predisposition for increased Phomopsis sp. infection (Stuckey, 1982, Ross, 1977), cracked seedcoats, and changes in seed composition (Ross, 1987).

Post harvest deterioration of seed in storage can occur, particularly if the seed moisture content is 13% or higher. Species of Aspergillus, Penicillium, Macrophomina, Fusarium and Rhizopus can infect seeds in storage and cause severe damage (Wolf and Cowan, 1975, Kueneman, 1985). Development of disease in storage is dependent upon the quality of seeds being stored, seed moisture content, the temperature of the drying and storage environments and the length of time in storage. (White, et al., 1976, Paulsen, et al., 1981, Dorworth and Christensen, 1968).

High moisture in a storage bin can cause heating due to high respiration rates. In the extreme, such heating can burn seeds (Wolf and Cowan, 1975).

Insect feeding on immature soybean pods can cause seed malformation, changes in protein and oil composition and increase the risk of infection by disease organisms. (Turner, 1967, Daugherty, 1964, Shortt et al., 1982). Three species of stink bug, southern green [Nezara viridula L.], green [Acrosternum hilare (Say)], and brown [Euschistus servus (Say)] are the most detrimental to seed quality (Todd and Herzog, 1980). Stinkbugs pierce the pod wall with their mouth parts and feed on plant juices in the developing seeds. Depending upon the stage of development, a seed may abort, become sunburned and wrinkled around the insect puncture, or become stained and discolored (Turner, 1967).

A yeast-spot disease organism (Nematospora coryli Peglion), which is transmitted through the salivary glands of the stinkbugs, may also contribute to the seed damage (Daugherty, 1967).

Green seed color is another quality problem. Green seeds result when plants die prior to maturity. This is usually associated with an early killing frost, but diseases or possibly severe drought could also cause early plant death. The percentage of green seeds is a grading factor and can increase the grain damage score. Green seed cotyledons are a serious problem for soybean processors because they produce an undesirable "red" oil when crushed. The pigment can be removed, at least partially, by special filtering (Wolf and Cowan, 1975), but the process is an addition to the normal bleaching procedure and is thus an extra expense.

Chemical Quality

The chemical constituents of soybeans, protein and oil, may be the most important factors in determining quality because the ultimate value of a soybean crop lies in the oil and protein meal produced from that crop. A survey of soybean processors in nine North Central states ranked oil and protein content as the most important among a group of nine quality characteristics (Murken, 1974). However, in the same survey at local county elevators, protein and oil were ranked lowest and foreign material and moisture ranked highest. Unlike moisture and foreign material, protein and oil contents are not used as grading factors and are therefore not considered in the price a county elevator receives for their beans. On the other hand, soybean processors produce and sell protein meal and oil, and thus place more importance on protein and oil content.

Until now, the expense and difficulty of obtaining accurate oil and protein measurements at the grain elevator has prevented the use of protein and oil as grading factors. However, with the development of the infrared light grain quality analyzer which can rapidly determine protein, oil and moisture percentages, some have predicted that soybean pricing will eventually be based on oil and protein content (Hurburgh, 1987).

By U.S. Grain and Feed Association regulations, soy protein meal is processed and marketed at either a 44% minimum protein level or at a high protein level between 48 and 50% (on a 12% moisture basis) (Wolf and Cowan, 1975). In processing, the soybeans are cracked, dehulled and the oil extracted. The remaining dehulled, defatted meal is the high protein meal. Hulls are added back to this meal in order to lower the protein to 44%. Cultivars currently being grown in the U.S. have approximately 40.5% seed protein and 21% seed oil on a dry weight basis (Hartwig, 1973). However, depending on the environment and cultivar, protein levels can be somewhat higher or lower than 40.5% in protein. Therefore, 49% meal cannot be made from some seed lots, and in such an instance, soybean processors try to raise the protein level by blending in higher protein beans (Updaw and Nichols, 1980).

Oil content is also important to soybean processors. The price per pound of oil is greater than the price per pound of protein meal. Even so, because more pounds of protein meal than oil can be produced from a bushel of soybeans, the protein meal usually has more economic value (Updaw and Nichols, 1980). The actual profit that a processor makes from the oil and protein meal at any given time is dependent upon the relative prices of the two, and processors typically want high levels of both in the soybeans they buy.

Other chemical constituents of soybean have been sometimes identified as traits that need to be altered in order to improve quality. The most important of these include trypsin inhibitors (Borchers, et al., 1948), low levels of sulfur containing amino acids (Wolf and Cowan, 1975), lypoxygenase (Axelrod et al., 1981), and linolenic acid content of soybean oil (Kalbrener et al., 1974). Trypsin inhibitors, which make up about 6% of the total soy protein (Hymowitz, 1985), inhibit protein digestion and cause pancreatic hypertrophy in poultry (Bray, 1964). These inhibitors are destroyed by the heat treatment that occurs during processing. Lypoxygenases catalyze the oxidation of polyunsaturated fatty acids in soybean oil. The oxidation products give the oil poor flavor quality (Kitamura et al., 1983). These enzymes are also destroyed with heat treatment. The instability of the polyunsaturated linolenic acid of soybean oil also contributes to poor flavor quality. Soybean oil is hydrogenated during processing to lower the concentration of linolenic acid. The methionine level in soy protein is considered to be too low for some animal rations, particularly for poultry. To solve this problem, the soy protein is either blended with grains such as maize that have higher levels of methionine or synthetic methionine is added to the protein meal (Wolf and Cowan, 1975).

All of the above traits currently have no economic value. However, there are end uses, usually those involving unprocessed soybean products, where genetic alteration of these traits could be important. For instance, if full-fat unprocessed beans were used as poultry feed (Paulding et al., 1986) a cultivar without trypsin inhibitors could be useful. Likewise, unprocessed soybean oil would probably benefit from having a lower concentration of linolenic acid. Because all of these traits are expensive to measure at the present time, it is doubtful that they could be used as grading factors in an overall definition of soybean quality.

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CHAPTER 2

Objectives of Genetic Selection

In the early years of this century, several thousand soybean strains were introduced from Asia (Hartwig, 1973). Because soybean is photoperiod sensitive, one of the initial tasks was to identify the potential adaptation areas for these accessions. A maturity group classification system was developed. Those materials adapted to northern most latitudes were placed in group 00 and those adapted to southern most latitudes were placed in Group X. The soybean's potential value as an oilseed was recognized and plant breeding was begun for high oil and adaptation to North Central states. The cultivars, Dunfield and Illini, released in the 1920's, resulted from this breeding effort and their oil content became the standard for succeeding cultivars (Brim, 1974). Soybean was also used as a forage during this time and prior to 1941, more soybeans were grown for forage in the United States than for grain (Hartwig, 1973). As soybean gained wider usage as a grain, breeding emphasis on seed yield increased. Early improvements in resistance to plant lodging, seed shattering and foliar diseases, increased soybean adaptability and helped make soybean a suitable grain crop for a wide geographical area (Brim, 1974).

Key Elements Breeders Have Stressed Through The Years

Brim (1974) noted two major objectives of soybean improvement programs: to increase seed yield and to increase seed quality. A third objective is the protection of current levels of yield and quality by increasing resistance to diseases, pests and environmental stress. Because high yield has always been the primary quality that farmers wanted in a new cultivar, it is the trait that has received the most attention of plant breeders. Studies, which have made side by side comparisons of old and new cultivars, have shown that significant improvement in soybean yield potential has occurred. In a test of Group I, II, III, and IV cultivars released between 1933 and 1971, Luedders (1977) found a total yield increase of 50%. In a similar test of Group II and III cultivars released between 1923 and 1974, Wilcox et al. (1979), found a total increase of approximately 30%. Boerma (1979) found that yields of cultivars in Maturity Groups VI, VII, and VIII had increased about 42% since 1914.

The emphasis that a breeding project places on disease and pest resistance is dependent upon the potential yield loss that the pest or disease causes and also its regularity of occurrence (Fehr, 1987). As soybean acreage increased in the United States, the occurrence of some diseases and pests became more frequent. The soybean cyst nematode (SCN) (Heterodera glycines) is a notable example. It was first identified in North Carolina in 1954 (Winstead et al., 1955), and since then it has been identified in 23 states (Riggs and Schmitt, 1987). The cyst nematode was recognized as a pest which would regularly reoccur on soybeans once a population became established in a production field, and because of this the USDA-ARS supported research in North Carolina to develop a SCN resistant cultivar. The cultivar "Pickett" was developed and released as a result of this effort (Brim and Ross, 1966). Nematode, both cyst and root knot (Meloidogine spp.), resistance has continued to be a major soybean breeding objective (Matson and Williams, 1965; Kinloch and Hinson, 1974; Kinloch et al., 1982).

A disease which has received major attention by soybean breeders is Phytophthora root rot caused by species of Phytophthora fungi. It frequently occurs in heavy-clay poorly-drained soils and plants which have the disease usually die (Athow, 1987). Because crop losses are so dramatic in fields that are infested with Phytophthora, much research has been directed toward finding genes for resistance to the disease (Kilen et al., 1974; Bernard et al., 1975; Laviolette et al., 1979) and incorporating those genes into cultivars.

There are other diseases for which genetic resistance has been identified. These include frogeye leaf spot caused by Cercospora sojina Hana (Athow and Probst, 1952), downy mildew caused by Peronospora trifoliorum de Bary var. manshurica (Dunleavy and Hartwig, 1970), powdery mildew, caused by microphoera diffusa Cke. and Pk. (Demski and Philips, 1974), brown stem rot caused by Phialophora gregata (Allington and Chemberl.) W. Gams (Sebastian et al., 1986), stem canker caused by Diaporthe phaseolorum (Cke. and Ell. Sacc. var. caulivora Athow and Caldwell. (Weaver et al., 1984), soybean mosaic virus (Kiihl and Hartwig, 1979), beanpod mottle virus (Ross, 1986), peanut mottle virus (Demski and Kuhn, 1975), soybean stunt virus (Milbrath and Tolin, 1977), cowpea chlorotic mottle virum (Boerma et al., 1975), and bacterial puslule caused by Xanthomonas camipestria pv. phaseoli (Ross, 1987). Resistance to one or more of the above diseases has been bred into or identified in existing cultivars.

In recent years resistance to insects has been an objective of some soybean breeding projects. Most of this research has been conducted in southeastern states where insects pose a greater threat to production (Kogan, 1980). While several insect species are pests, the genetic resistance which has been identified (Van Duyn, 1971) seems to have some effectiveness against most of them (Lambert and Kilen, 1984). Improved insect resistant breeding lines have been released as germplasm (Elden et al., 1982, Burton et al., 1986) and one insect resistant cultivar 'Crockett' has been released in Texas (G. R. Bowers, personal communication).

Another soybean breeding objective is resistance or tolerance to environmental stress. Soybean cultivars have been evaluated for tolerance to drought stress and some apparent genetic variation for the trait has been identified (Specht et al., 1986). Some genotypic differences in germination cold tolerance have been identified (Unander et al., 1986). Genetic sources of resistance to iron deficiency chlorosis in soybean grown on calcareous soils have been identified and used in breeding programs (Bahrenfus and Fehr, 1980; Fehr and Cianzio, 1980; Prohaska and Fehr, 1980). Soybean cultivar tolerance to aluminum in low pH soils has also been investigated (Sartain and Kamprath, 1978).

There has been many studies aimed at characterizing the genetic variation for protein and oil content in soybean and the genetic correlations between oil, protein, and seed yield (Burton, 1985). Yet for most soybean breeding projects, altering protein and oil concentration has been a low or nonexistant priority. Rather the primary breeding goal has usually been high yield with maintenance of protein and oil at acceptable minimum levels, ca. 41% protein and 20% oil. The well documented negative relationship between protein and oil has meant that selection for either trait alone has resulted in a decline in the one not selected (Brim and Burton, 1979; Burton and Brim, 1981). Likewise, yield and protein are often negatively correlated and it has been difficult to increase both simultaneously (Brim and Burton, 1979). As previously discussed, soybean producers, who are the primary clientele of soybean breeders, do not receive payment for the beans they produce according to chemical constituency. As a result, they have shown no interest in cultivars with high oil or high protein and this lack of interest has influenced plant breeding objectives.

Three cultivars have been released that are 8 to 12% higher in protein concentration. 'Protana' and 'Provar' were developed in Indiana and Iowa, respectively, and released in 1969 (USDA-ARS, 1969).

Because the yielding ability of these cultivars was less than other varieties being grown at the time, neither gained much acceptance by farmers. The third cultivar, 'Tracy', was developed in Mississippi and because it had good yielding ability and resistance to Phytophthora rot and some foliar diseases, it achieved wide usage in Southeastern states. The cultivar 'Ransom', developed in North Carolina (Brim and Elledge, 1973) has a higher than average oil concentration, 23%. It achieved wide usage because of its high yielding ability and not because of its high oil content.

Institutional Influences on Genetic Selection

Genetic research on soybean was begun by USDA early in this century with the coordination of germplasm acquisition from foreign countries, primarily in Asia (Hartwig, 1973). This has continued to the present. The USDA maintains two germplasm collections. One in Stoneville, Mississippi of Group V to Group X materials and one in Urbana, Illinois of Group 00 to Group IV materials. The USDA also annually coordinates and conducts two regional evaluations of advanced breeding lines developed by publicly funded soybean breeding projects, one for the North Central states for materials in Group 00 through Group IV, and one in the Southern States for materials in late Group IV through Group VIII. In the regional testing program, soybean lines are tested for a number of different traits including yielding ability, plant lodging susceptibility, maturity, height, seed protein and oil concentrations, and resistance to nematodes, insects, and some diseases. Decisions about the release of a line as a cultivar is highly dependent upon the performance of the line in the regional tests.

In the 1960's soybean breeding research at state agricultural experiment stations increased. Unlike the USDA which emphasized germplasm development and basic research, the state supported projects emphasizing cultivar development. Privately funded soybean breeding increased with the passage of the Plant Variety Protection Act of 1970 which gave a cultivar developer exclusive control over marketing and distribution of the cultivar (Fehr, 1987).

There are two major institutional influences on genetic selection. One of these is the Seed Branch of the USDA which administers the Federal Seed Act of 1939 (USDA Agricultural Marketing Service, 1975). This Act is essentially a truth-in-labeling law that gives regulations governing commerce in seeds. The way this law is administered determines the kind of cultivar a plant breeder can make available to farmers. The other institutional influence is the funding agency which supports particular research projects and thereby emphasizes certain research objectives.

In the Federal Seed Act (Section 101, No. 12), a "variety" is defined as "a subdivision of a kind which is characterized by growth, plant, fruit, seed, or other characters by which it can be differentiated from other sorts of the same kind." This definition is quite general which allows seed regulatory agencies at the state and federal levels to be restrictive or liberal in their judgement of whether or not a breeding line is genetically pure and distinct from other varieties. All plant breeders develop cultivars according to the way the seed regulatory agencies interpret the variety definition. Questionable constraints on the kind of plant materials that can be released as varieties can occur if "other characters" are interpreted to mean only external morphological characteristics, or if the definition is interpreted to mean that all plants of a variety must be genetically and phenotypically identical. Because of the need for identification and proof of uniqueness, plant breeders are required to make a detailed description of each cultivar released. The USDA Form (LMGS-470-57) which is used for this purpose for soybean has 23 descriptive categories. One of these categories is for rating disease reaction to 25 pathogens.

The other major institutional influence on genetic selection is the funding agency. For a private plant breeder, research is funded by profits from the sale of variety seed to farmers. Thus, research objectives are closely tied to the varietal needs and wants of farmers. Funding for publicly supported soybean breeding projects is usually not earmarked for any particular research objective. However, the institutions that administer public funds (USDA-ARS, USDA-CSRS, State Experiment Station) for soybean breeding often try to emphasize certain broad research goals in the way that they allocate the funds. For instance, in the Six Year Implementation Plan (1986-1992) of the USDA-ARS (USDA-ARS, 1985), the following plant breeding related objectives were listed as those which would be given highest funding priority: (1) Expanding capabilities for preserving, evaluating and enhancing germplasm; (2) technologies for gene transfer and expression; (3) technologies for lowering production costs and improving product quality; (4) biocontrol technologies for major crop species; and (5) methods for genetically and metabolically controlling the quality parameters of plant and animal raw agricultural commodities and products.

Commodity organizations also influence plant breeding objectives by the way in which they allocate funds. There are state soybean producers associations which support soybean research through funds generated by the check-off program, and a national organization, the American Soybean Association (ASA), which supports research through a research grants program. ASA funds come from individual state organization contributions. In 1985, the state soybean producers association provided some support to 22 varietal development programs in 18 states (American Soybean Association, 1985). The decisions about which research projects to fund is made by a research committee of farmers who evaluate proposals submitted by soybean scientists. Typically each research committee has an advisory board made up of scientists and administrators from the state experiment stations and land grant universities which conduct agricultural research. The advisory board screens the research proposals and gives them priority ratings. This evaluation is given to the research committee which independently decides which ones will be funded (B. E. Caldwell, personal communication). The research grants program of the ASA is administered in exactly the same way. The research priorities of the soybean producers themselves are usually reflected in these funding decisions. Project descriptions for each state reflect those aspects of soybean production which are of particular concern for that state, i.e., stem canker in Alabama, Phytophthora rot in Iowa, double cropping in Missouri, etc. (American Soybean Association, 1985).

Future Objectives for New Materials of Non-Traditional Use

While most soybean breeding has been directed toward increasing or protecting productivity, a considerable amount of research has also been aimed at developing germplasm with novel seed traits that would fit particular end uses and markets. As usually visualized, these novel types would be sold outside the grain trade (probably on a contract basis) and thus have the opportunity to bring a premium price. The development of the cultivar 'Vance' offers a good example of soybean breeding for a special end use. 'Vance' was derived from a cross between the cultivar 'Essex' and a wild soybean (Glycine soja) line. It has very small seeds (8.8/100 seeds) which make it very suitable for use in natto, a Japanese food product. Currently this cultivar is being grown in North Carolina and Virginia and is being sold directly to a Japanese importer at a price that is above the soybean grain market price.

Tofu, is another soybean food product that could be made from a specialty variety. While tofu can be made from any soybean, high protein seeds with yellow seedcoats and hila are preferred (Fehr, 1987). The variety 'Vinton' which has 44.9% protein was developed for this purpose (Bahrenfus and Fehr, 1980).

Vegetable cultivars have been produced in the past. These have usually tended to be large seeded types (greater than 20g/100 seeds) with low oil content (Hartwig, 1973). Several vegetable cultivars have been developed.

Feeding poultry full-fat unprocessed soybeans has been considered by nutritionists (Meran et al., 1973; Latshaw and Clayton, 1976). There are economic conditions related to the relative prices of oil extracted soybean meal and unprocessed beans that could make it more economical to use full fat beans as poultry feed (Paulding et al., 1986). A cultivar that is higher in protein and low in oil might be very useful as an unprocessed livestock feed. In addition, removal of the trypsin inhibitors through plant breeding would eliminate the need for any heat treatment of the beans prior to feeding (Orf and Hymowitz, 1979). Increasing the methionine content of the storage proteins could also eliminate the need for the addition of synthetic methionine to the animal rations (Howell et al., 1972).

Much progress has been made in the genetic alteration of fatty acid composition of soybean oil. Soybean germplasm has been developed with oil having a low linolenic acid concentration (Wilcox et al., 1984; Hammond and Fehr, 1983a; Wilson and Burton, 1986), high stearic acid concentration (Hammond and Fehr, 1983b), high oleic acid (Carver et al., 1986), and low palmitic acid concentration (J. W. Burton, unpublished data). As previously discussed, the high linolenic acid concentration in soybean oil has been identified as the major contributor to poor stability and flavor of soybean oil. Thus, the new germplasm should provide plant breeders the capability of producing soybean cultivars that have several different oil qualities. It is possible that soybean oil processors would pay a premium for a cultivar with a particular oil quality, or such a cultivar could be grown under contract to a domestic or foreign buyer. The same would be true of cultivars which lack lipoxygenase.

Most soybean breeding projects will probably continue to have higher yield and stability through pest resistance as their main objectives. However, as markets for specialty varieties become known, farmer demands for such varieties will increase, and soybean breeders will respond with attempts to develop them.

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CHAPTER 3

Genetic Influences on Quality

Seed quality is influenced by both plant genotype and the environment in which the plant is grown. Genotypes can often be altered using classical plant breeding methods so that changes in seed quality result. Likewise, some environmental factors can be changed such as soil fertility through fertilizer application or water status through irrigation. However, many environmental factors cannot be changed. Weather and soil type are examples. Even so, plant breeding can offer a partial solution to problems caused by environmental variation, through consideration of genotype-environment interactions. Direct genotypic influences on seed quality and interactions between the genotype and environment that affect seed quality will be discussed in the following.

Quality Attributes Under Genetic Control

Seed coat and cotyledon color are controlled by a relatively small number of genes (Bernard and Weiss, 1973). Likewise, small numbers of genes are usually involved in disease resistance (Palmer and Kilen, 1987). In cases like these where traits are simply inherited, genetic alteration is not difficult provided the presence or absence of gene expression can be determined. Thus, the seed quality traits identified in Chapter 1 that are related to seed color and disease can be easily manipulated using standard plant breeding methods if genes for disease resistance have been identified in the soybean germplasm collection. (Specific examples of genetic resistance are described in Chapter 6.)

Protein and oil concentration (percentages) in soybean seeds and seed size are quantitative traits that are known to be under the influence of many genes. These can also be changed by classical plant breeding methods, but the task is usually more difficult. The challenge to plant breeders is mainly that of incorporating the large number of genes affecting the trait into an agronomically acceptable cultivar. This is complicated by the fact that genetic alteration of one trait frequently leads to undesirable changes in other plant characters. Because seed size is of very minor importance with respect to seed quality, I will limit the remainder of this discussion to a consideration of seed protein and oil concentration.

When quantitative inheritance is involved, knowing the heritability of a trait is the key to determining an appropriate plant breeding strategy for changing the trait. Because a quantitative trait is controlled by many genes, the expression of the trait is variable depending upon which genes are present in a given plant. Also, the trait is usually influenced by environmental conditions, which also contributes to the variation in expression. Heritability is a measure which estimates the proportion of the total variation in expression that is due to strictly genetic influences. Thus, a trait with high heritability is subject to less environmental influence which means that the genetic worth of a particular plant is more easily determined. This usually means that progress in changing the trait through breeding is more rapid.

Johnson and Bernard (1963), Brim (1973) and Burton (1987) have presented heritability estimates for quantitative traits that are usually measured in soybean breeding populations. The estimates were taken from several independent studies of different populations of soybean lines. Heritability estimates for seed protein percentage ranged from 51% to 92%. Seed oil estimates of heritability were similar, ranging between 51% and 93%. By comparison, seed yield estimates are lower, between 0% and 73%. This suggests that seed composition is less affected by environmental factors than seed yield. Thus, the genetic worth of a soybean line as it pertains to protein and oil composition is easier to determine than its genetic worth relative to seed yield.

Yield-Quality-Resistance Interaction

Breeding a cultivar for disease or pest resistance requires that resistance genes be incorporated into a high-yielding, agronomically acceptable genotype. If the resistance genes are located in a high yielding adapted cultivar, then the transfer of resistance can usually be accomplished without yield loss. Such would be the case with resistance to soybean mosaic virus (SMV). There are currently available high yielding SMV resistant cultivars (e.g., Young [Burton et al., 1987]). On the other hand, when resistance genes must be acquired from non-adapted plant introductions, transfer of resistance without some yield loss is difficult to achieve. Resistance to Phomopsis, Cercospora kikucii, and stinkbug would fit this category. Resistance to any of the organisms described in the first chapter would have the effect of protecting seed quality to some degree. However, a soybean breeder is not likely to place much emphasis on resistance to any of these pests unless they cause a loss in crop value with some regularity (Fehr, 1987).

A major difficulty in selection for altered seed protein or oil composition in most soybean populations has been the exsistance of negative genetic correlations between protein percentage and the two other economically important traits, yield and oil percentage. Thus, selection for increased protein usually results in decreases in percentage oil and often in decreased yield (Brim and Burton, 1979; Wehrmann et al., 1987). Similarly, selection for increased seed oil percentage results in decreased protein (Burton and Brim, 1981). Percentage protein and percentage oil were found to be negatively correlated in 12 soybean populations investigated in five separate studies (Table 3-1). Most of these correlations had absolute values greater than 0.50. However, weaker relationships between the two traits do occur. In one population, derived from the cross Woodworth X PI 159,764, the genetic correlation between protein and oil was only -0.15 (Simpson and Wilcox, 1983). Negative correlations between percentage protein and yield, though frequent, were usually not great, only two having absolute values greater than 0.50. One population, derived from the cross, Woodworth X PI 159,764, had a positive genetic correlation of 0.54 between protein and yield (Simpson and Wilcox, 1983).

When considering the problems of genetically increasing the quantity of protein produced by a soybean crop, there must be a recognition of both the producer's desire for high yield and the soybean processor's desire for high protein percentage and acceptable oil levels. Thus, breeding methods have been varied depending upon the breeding goals. The negative relationship between protein and oil has led some investigators to attempt to increase protein indirectly by selection for low oil. This has some economic advantages in that percentage oil can be measured rapidly and nondestructively in soybean seeds by nuclear magnetic resonance (NMR) spectroscopy. Hartwig and Hinson (1972) selected for low oil using a backcrossing approach with an unadapted high protein line and the cultivar Bragg as the recurrent parent. Miller and Fehr (1979) found that one cycle of recurrent selection for low oil indirectly increased protein 0.8 percentage units, which was about half the progress obtained with direct selection.

Early generation mass selection was used successfully to increase protein in a composite population of F_2 plants from four G. max X G. Soja crosses (Erickson et al., 1981). Mass selection among F_2 plants, followed by mass selection among F_3 plants, increased the mean of the F_4 generation 7.1%.

Index selection has been used either to increase the efficiency of selection for percentage protein by adjusting for covariation of other traits, or it has been used to change percentage protein and some other trait simultaneously. For example, correlations between percentage protein and the sum of percentage protein and oil are positive (Thorne and Fehr, 1970; Shorter et al., 1976; Openshaw and Hadley, 1983). Thorne and Fehr (1970) found that selection for an increased sum of oil and protein increased protein by 3.4% while decreasing oil by only 0.5%. Openshaw and Hadley (1983) predicted the gain in protein resulting from selection for oil + protein to be 1.4% of the midparent. 'Desired gains' indexes were also used to increase percentage protein while changing percentage oil or holding it constant. These indexes were reasonably effective in controlling changes in both traits simultaneously.

Increased protein yield can also be accomplished by selection for increased yield, provided percentage protein does not decline significantly. In this respect, recurrent restricted index selection could be used to hold protein constant while increasing yield. In two cycles of selection, using such an index, yield increased from 32.0 to 32.5 bu/acre while protein and oil remained constant at 45.8% and 17.8%, respectively (Holbrook, 1985). It might be possible to select for protein yield directly; however, with this approach there is the risk that percentage protein would decline. Other approaches include independent culling and tandem selection. A kind of tandem selection was used with some success by Sebern and Lambert (1984) to identify high, intermediate and low percentage protein groups in the F_2 or F_3 generations, followed by selection for yield within the groups in later generations. Higher protein has also been incorporated into high yielding germplasm through backcrossing. In recent research low-yielding, high-protein germplasm was backcrossed twice to three high-yielding parents. Nineteen percent of the lines derived from the second backcross were significantly higher in percent protein and not different in yield when compared to the high yielding parents (Wehrmann et al., 1987).

Genotypic Variability

There is a wide range, approximately 15 percentage points, in seed protein percentage among lines of the U.S. soybean germplasm collection. About 10% of these have a protein percentage higher than 44.5% (Hartwig, 1979). The wild soybean species, G. soja, with a protein content that is typically greater than 45%, has also been used as a source of high protein germplasm (Erickson et al., 1981). Seed oil percentage for lines in the U.S. germplasm collection acquired before 1970 range between 13.2% and 23.5% (Wilcox, 1983). Because most currently grown cultivars have between 20 and 23% oil, there appears to be more opportunity for increasing percent protein than percent oil with the germplasm resources currently available.

With the breeding methods mentioned in the previous section, lines have been developed with higher protein content than standard cultivars and similar yielding ability. Three examples of such lines have protein percentages between 44.2 and 45.5 and were recently evaluated in the USDA Uniform Soybean Tests (Table 3-2). With these three lines it should be noted that when protein content was higher than the check cultivars, oil content was lower.

The seed composition of the above three lines is not typical of the soybean cultivars currently being released because alteration of seed composition is not a major concern of most soybean breeding projects. A good picture of seed protein and oil contents of typical soybean breeding lines can be obtained from the results of the USDA Uniform Soybean Tests. These tests contain elite lines which are being evaluated for possible release as cultivars. High yielding cultivars are included as checks for comparison. The Uniform Tests are organized by maturity group and are tested in their area of adaptation which includes several states. Each year new soybean lines are added to the tests, along with the check cultivars and some promising lines from the previous year's tests. Yield, disease susceptibility, and other triats including protein and oil are measured on these materials.

The lines and check cultivars which were entered in the 1986 Uniform Soybean Tests of the Northern States (Group I to IV) varied in percent protein from 37.6 to 42.6 and in percent oil from 19.2 to 23.2 (Table 3-3). In the Southern Region (Group V to VIII), overall protein percentages of the entries were a little higher (between 39.5 and 43.3) and oil percentages were a little lower (between 19.3 and 22.3) than those in the northern states. The entries in the tests were high yielding lines and these seed protein and oil levels are indicative of the breeding lines that most soybean breeders are currently working with.

Mutagenesis has not been widely used in soybean breeding to create genetic variability. Because mutagenesis causes random changes in the genome, many undesirable mutations occur. Agronomic quality and productivity usually decline (Weber and Fehr, 1967). Ethyl methane sulfonate (EMS) has been successfully used to induce genetic mutations that alter the fatty acid composition of soybean oil (Hammond and Fehr, 1975; Wilcox et al., 1984). In these cases, productivity suffered but the desirable genetic changes occurred at a single gene loci. Thus, backcrossing the desirable gene into a highly productive type has not been difficult. Mutagenesis has not been used to develop genetic resistance to diseases. Soybean breeders have continued to find the needed resistance to genes in the existing germplasm collection. Mutagenesis will probably not be used to develop disease resistance unless genetic possibilities in the germplasm collection are exhausted. Also, the new genetic engineering methods, are likely to replace the random mutagenesis of the past with more specific directed genetic mutations.

Genetic Versus Environment

In any plant population, variation in the expression of a quantitative trait is due to genetic and environmental influences and an interaction between the two. In defining issues related to the interaction of genotype and environment in plant breeding, it is helpful to consider environmental variation in a continuum from predictable to unpredictable (Allard and Bradshaw, 1964). Predictable variation is due to those conditions which can be controlled in some way (e.g., irrigation) or those which have permanent characteristics (e.g., photoperiod and soil type). Weather-related conditions generally contribute most to unpredictable variation.

Most problems in seed quality that arise because of weather have no real genetic solutions. Sometimes, genetics can lessen the impact of a weather-related problem. For instance, the hard-seed coat genotype develops less seed disease when harvest is delayed after maturity (Potts et al., 1978). Other genetic sources of resistance to fungal seed pathogens (Ross, 1985) lessen the problem but do not eliminate it. Many seed disease problems are related to cultural practices and harvest (Kmetz et al., 1979; Wilcox et al., 1974; Spilker et al., 1981). Usually changes in farming, harvesting and storing practices are much more likely to be effective in controlling seed disease than varietal disease resistance.

Most soybean breeding programs have regional testing programs for evaluation of genotypes across a wide array of environments. A genotype is selected from these tests on the basis of ability to perform well in all environments. Statistical analyses have been developed to determine the relative environmental stability of cultivars (Lin, 1987). Evaluation and selection of stable cultivars is the most common way that environmental influence is moderated by genetics. The other way to moderate environmental influence is to attempt to tailor a variety for a particular environment. This can be quite successful if the environment can be defined. Breeding for disease resistance fits this category.

Genetic Versus Management Practices

Management practices play a very important role in controlling seed diseases. For instance, disease inoculum on plant residue from a previous crop can increase the level of infection (Kmetz et al., 1979). Choice of cultivar is also important. Growing cultivars that differ in maturity can spread harvest time and help prevent weathering damage to seeds because of delayed harvest (Johnson, 1987). In some environments, a cultivar can escape a pest or stress problem. For instance in Georgia, it is possible to escape damage due to insects by planting earlier maturing varieties (H. R. Boerma, personal communication). There is also evidence that fungicide application at appropriate times can reduce seed diseases (Ross, 1975).

It is possible to choose cultivars that have more or less oil and/or protein on average than other varieties. However, it should be recognized that any variety will vary in seed composition across environment. In this case too, some cultivars are more stable than others.

In the Uniform V tests, the cultivar Essex averaged 41.6% protein in 1986 and 43.4% in 1985 (Table 3-4). Over locations within a year, Essex varied between 2.7 percentage

Other lines in the test were less stable. The line, D81-7857, varied 5.6 percentage points in 1984 and the cultivar Hutcheson varied 7.2 percentage points in 1986.

Genetic Versus Storage

Little is known about the relationship between seed genotype and storage (Tekrony et al., 1987). While there is some evidence that there are some genotypic differences in the storability of seeds (Wein and Kueneman, 1981; Minor and Paschal, 1982; Ellis et al., 1982), it is possible that the condition of seeds at the time of storage is the main determinate in storagability (Egli et al., 1979).

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Table 3-1. Genotypic Correlations Between Seed Protein and Seed Oil Percentages and Between Protein Percentage and Yield.

Population		Johnson et al (1955)		Thorne and Fehr (1970)		Shorter et al (1976)		Simpson and Wilcox (1983)				Openshaw and Hadley (1984)	
		1	2	3	4	5	6	7^a	8^a	9^a	10^a	11	12
% oil	genotypic	-0.48	-0.70	——	——	-0.96	-0.35	-0.15	-0.96	-0.72	-0.36	-0.83	-0.68
% oil	phenotypic	-0.48	-0.69	-0.66*	-0.58*	-0.79*	-0.24	——	——	——	——	-0.80*	-0.65*
% yield	genotypic	-0.64	-0.12	——	——	——	——	+0.54	-0.74	-0.40	-0.20	——	——
% yield	phenotypic	-0.33	-0.08	-0.21	-0.27	——	——	——	——	——	——	——	——

* = Significant at $\alpha < 0.5$

a = Random F_5 lines from crosses between unadapted high protein lines and adapted average protein lines (UH X AA).

Table 3-2. Mean Performance of Check Cultivars and Breeding Lines with Higher Percent Seed Protein

Line	Yield	Protein	Oil
	bu/acre	——— %	———
D82-4098[a]	45.8	44.2	18.1
Centennial	43.8	42.9	19.0
N84-1256[b]	37.0	45.5	18.7
Check Cultivar[c]	37.5	41.5	21.0
LN82-4049[d]	45.4	44.8	20.2
Sparks	44.0	41.2	21.5

a = Tested in the Regional Preliminary VI, The Uniform Soybean Tests - Southern Region, 1984.

b = Tested in five North Carolina environments.

c = Braxton, Ransom, or Gasoy 17.

d = Tested in the Regional Preliminary IV A, The Uniform Soybean Tests - Northern States, 1985.

Table 3-3. Means and Ranges for Protein and Oil Percentages of Breeding Lines in the 1986 Uniform Soybean Tests for the Northern States and Southern Region.

Test	No. of Test Sites	No. of Lines	Protein		Oil	
			Mean [a]	Range	Mean	Range
Uniform I	4	10	40.4	39.2 - 42.4	19.8	19.2 - 20.6
Uniform II	4	15	39.5	37.6 - 42.2	21.0	19.8 - 22.1
Uniform III	5	25	39.5	37.8 - 41.9	21.8	20.3 - 23.2
Uniform IV	5	18	40.5	39.6 - 42.6	21.2	20.1 - 22.4
Uniform V	9	12	41.1	40.0 - 42.3	20.6	20.0 - 21.3
Uniform VI	9	12	42.3	40.9 - 43.3	20.0	19.3 - 21.2
Uniform VII	6	12	41.0	39.8 - 42.2	20.9	19.7 - 22.0
Uniform VIII	5	12	41.8	39.5 - 43.3	20.9	20.0 - 22.3

a = The mean percent protein for each test averaged over lines and test locations.

Table 3-4. The Percent Seed Protein Average and Range Over Nine Locations for Five Entries of the 1984, 1985, and 1986 Univorm V Sybean.

	1984		1985		1986	
	Average [a]	Range [b]	Average	Range	Average	Range
	%					
Essex	42.4	3.8	43.4	2.7	41.6	3.3
Forrest	39.5	4.8	40.9	4.0	40.0	3.6
D81-7857	38.4	5.6	39.9	4.2	40.6	5.2
S80-2959	40.8	3.4	41.7	3.7	40.9	4.8
Hutcheson	40.3	3.3	40.3	2.9	40.8	7.2

a = Protein averaged over nine test locations.

b = The difference between the highest and lowest protein percentages.

CHAPTER 4

Role of Public Versus Private Plant Breeders

Differentiation of Role

Private industry investment in soybean breeding has been a relatively recent development. Prior to the passage of the Plant Variety Protection Act in 1970, there were only six companies with one plant breeder, each engaged in soybean breeding. Since then, an additional 25 companies and 61 breeders have been added to the private soybean breeding industry (Williams, 1987). Under the Plant Variety Protection Act, certificates of plant variety protection can be issued which assures the "developers of novel varieties of sexually reproduced plants . . . exclusive rights to sell, reproduce, import or export such varieties" (Claffey, 1981). It was this guarentee of exclusive rights to a novel soybean variety that enticed private seed companies to invest in soybean research. Thus, the role of the private plant breeder is to develop novel soybean varieties which can be sold at a profit.

Public soybean breeders have always been involved in varietal development. Yet, they have had and continue to have a larger role than this in soybean breeding science. Strosnider (1984) gives the following as the roles or responsibilities of public breeders: (1) teach and train students as future plant breeders; (2) conduct "basic" research; and (3) cultivar development of minor and regionally-adapted crops. This latter would obviously not apply to soybean breeders. There is general agreement among those concerned with this issue that training students is an important and appropriate responsibility of public breeders and most agree that public breeders should conduct basic research. The difficulty derives from the effort to define which research is basic and which is not. Strosnider (1984) suggests that basic plant breeding research is the investigation of imaginative breeding systems and exotic breeding stocks. He uses the terms "germplasm enhancement" to describe an activity wherein public plant breeders identify desirable genes in introduced accessions and improve the genetic background of those genes to the point that the germplasm can be exploited by the private sector. Alternatively, Ryder (1984) argues that plant breeders who have handled the germplasm through the entire enhancement process are best able to make use of the materials for cultivar development. He objects to the assignment of only germplasm enhancement to public breeders and only cultivar development to private breeders as being "unfair, inefficient, artificial and counter-productive".

The changing role of publicly-supported plant breeding research was discussed at the 1982 Plant Breeding Research Forum sponsored by Pioneer Hi-Bred International, Inc. In the report from this conference, which was attended by both public and private plant breeders and administrators, the joint effort between public and private breeders was affirmed as being mutually beneficial. Furthermore, the competition between the public and private breeders of crops such as soybeans was considered to be a healthy situation for the following reasons: (1) there is no assurance developing varieties of self-pollinated species will be profitable enough for private companies to justify continued research investment; (2) it is not possible to draw a line separating basic from applied plant breeding; and (3) there is no clear division between germplasm enhancement and cultivar development (Pioneer Hi-Bred International, Inc., 1982).

There is general agreement that increased support for basic research is needed, particularly that involving the collection, assessment and development of germplasm resources (Ryder, 1984; Strosnider, 1984; Pioneer Hi-Bred International, Inc., 1982). Plunknett and Smith agree that this is needed simply to maintain current levels of crop productivity. The average lifetime of a soybean cultivar in the U.S.

is five to nine years (Duvick, 1984), which is due in part to the dynamic nature of the agroecosystem (Plunknett and Smith, 1986). The sudden appearance of a disease, changes in climate, water or soil condition, or changing cultural practices can necessitate the replacement of a cultivar with one more adapted to the new environment. This situation is not likely to change. The new genetic engineering technologies, such as protoplast fusion, if successful, will be a useful tool in cultivar development but will not eliminate the seed for traditional plant breeding research activities (Sprague, 1980; Hansen et al., 1986).

Rationale for Differentiation

Private plant breeding programs have basically one goal, that is the development of an improved cultivar that can be marketed and profitably sold to farmers. This permits a concentrated investment of resources for cultivar development that is usually much greater than a similar investment by a public plant breeding program. For example, in 1983 Asgrow Seed Company made 1,200 crosses combining genetically different material and screened 120,000 lines with a professional staff of five Ph.D. plant breeders (Asgrow Seed Company, 1983). By comparison, the public soybean breeding program at North Carolina State University in a typical year makes approximately 6 crosses aimed at cultivar development and screens approximately 1,200 lines from agronomic performance. At North Carolina State University as at most public institutions that conduct soybean breeding, research funds and scientists' time is directed toward a variety of activities that are not directly related to cultivar development, such as teaching; germplasm evaluation; devising and testing breeding methodologies; inheritance studies, etc. Without a profit motive, publically funded soybean breeders are usually under less pressure to develop and release cultivars than private soybean breeders. Publicly funded soybean breeders are also more free to conduct long term research projects which have a low probability of yielding any immediate economic return. Because of the "high risk" nature of basic research, it is likely that it will only be conducted by public institutions (Pioneer Hi-Bred International, 1982).

Breeding for Specific Markets

Cultivar development of low volume crops or crops with a minimum profit potential for seed companies must be done by public institutions (Strosnider, 1984). It is USDA-ARS policy to "develop varieties when it has been determined that a need exists and this need may not be met by any cooperative or individual plant breeding program" (Hanna, 1985). Soybean varieties for special markets may fit this category. If the specific market for such a variety were relatively small, it could be profitably grown on only limited acreages. In this case, a private company would not consider varietal development to be a worthwhile investment of resources. Attractiveness of special variety development to private investment would likely grow in proportion to the market size for the variety.

A recent example of this, is the development and release of the small seeded cultivar, 'Vance'. 'Vance' was originally developed by the Agricultural Experiment Station in Virginia for use in producing beansprouts. However, it was found to be more suitable for use in making the Japanese food product, natto. Because of this it is currently being grown in North Carolina and Virginia on a contract basis for direct sale to a Japanese importer.

As the profitability of producing grain-type soybeans has declined in recent years, interest in soybean varieties for special end uses and markets has increased. Current research at various public institutions on genetic alteration of protein and oil quality and quantity (Burton, 1985; Wilcox, 1985) may eventually result in the development of altered protein and oil varieties. It is possible that specific markets can be found for these new varieties.

Funding

Soybean breeding by a private company is funded by profits from the sale of seeds of the varieties the company produces. If soybean varieties are not profitable, then the funds come from some other division of the company that is profitable. Funding decisions are based on company managers' assessment of the market potential for soybean varieties with particular characteristics, e.g., maturity group, resistance to a disease, etc.

There are four sources of public funding for soybean research. These sources and their relative contribution in 1984 are state appropriations (37%), USDA-ARS (29%), Hatch formula (10%), funds to land grant universities, and contracts, grants and cooperative agreements from federal, state, and farmer check-off sources (24%) (American Soybean Association, 1985). In the 1980's, farmer check-off has amounted to between 7.4 and 8.1% of the total soybean research funding. Grower funding varies a great deal among soybean producing states. In 1984, grower funding amounted to 25.7% of the total soybean research budget in Nebraska while in Ohio there was no grower funding.

Even though studies measuring return to investment in agricultural research show rates of return above 15%, state and federal support (in real dollars) for agricultural research has remained nearly constant since 1965 (Pioneer Hi-Bred International, Inc., 1982). In recent years, plant breeding positions in public institutions have become vacant, they have been converted to genetic engineering positions so that research in biotechnology can be emphasized. This has meant an overall decrease in funding of traditional plant breeding research (Hansen, et al., 1986). This reduction in public support for plant breeding is generally viewed with great concern (Strosnider, 1984; Ryder, 1984; Hansen et al., 1986; Pioneer Hi-Bred International, Inc., 1982). In the opinion of F. A. Bliss (1984), "Continued reduction in public support may limit the number and diversity of new cultivars produced by both public and private breeders, the flow of new knowledge and plant materials to seed companies, the ability of public breeders to pursue innovative high-risk ideas, and the continued supply of broadly trained plant breeders".

Alternate means of financing public plant breeding research are being explored. One suggestion - increased involvement by private industry in supporting public plant breeding. For instance, a private company could support graduate student training and research (Bliss, 1984). It is also suggested that private industry could support research which benefits the industry itself (Pike, 1984). Some state universities are considering patents on products of their plant breeding research as a means of generating revenue (Pioneer Hi-Bred International, Inc., 1982). Increased funding from commodity organizations is another possibility. All of the above are criticized because funding of this nature is usually unpredictable and tied to particular short range goals. It does not provide for the long term higher-risk research that requires a continual resource commitment. A recent suggestion has been the release by State Agricultural Experiment Stations of soybean varieties by the brand name "Variety Not Stated" with royalties. This idea has not been viewed favorably by either public or private soybean breeders (Commercial Soybean Breeders, 1987). It is believed that such a system would tend to shift more resources toward short term basic research, impede the free flow of germplasm among experiment stations, and limit a farmer's ability to know whether or not two varieties are identical.

The answer to the above problems is, of course, increased public investment in plant breeding. Soybean yields in the United States have increased 50% since 1950. At least half of this gain is due to an increase in the genetic potential which has resulted from traditional plant breeding. Legislators and seed company customers need to recognize that this was made possible through a cooperation between public and private soybean breeding (Pioneer Hi-Bred International, Inc., 1982). Continued soybean improvement and maintenance of current levels of productivity are in jeopardy if public investment in soybean breeding science decreases.

Future Roles

It is doubtful that the roles of private and public soybean breeders will change very much in the future. Private breeders will continue to concentrate on varietal development because it is the most profitable activity for a seed company. Germplasm enhancement, basic soybean breeding research and student training will continue to be the main activities of public soybean breeders. Because commodity groups still have some influence with AES administrators, it is likely that most public soybean breeders will still be expected to release varieties. However, in both USDA-ARS and land grant universities, basic research achievements and their publication receive more recognition than releasing a variety in terms of professional development and promotion. Thus, variety release is usually a by-product of the basic research and germplasm enhancement activities.

Major changes in chemical constituency of soybean seed or some other seed quality trait will most likely be initially developed by public plant breeders. Private plant breeders have until now concentrated on high seed yield and yield stability through disease and pest resistance. Therefore, most of the germplasm with improved seed quality traits is located within public plant breeding programs. Once improved germplasm is released, private breeders will utilize it provided a marketable variety can be derived from it.

Another role which will probably accrue to plant breeders is testing genetically engineered plant materials and possibly incorporating them in their breeding program. This kind of activity would be performed by the plant breeding project most closely associated with the research organization which did the genetic engineering. Otherwise, the materials would likely be tested on a contract basis by a plant breeding project outside the organization.

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CHAPTER 5

Variety Release

Number of Varieties

Prior to 1946, 194 soybean cultivars were released in the United States and Canada (Table 5-1). Nearly all of these were plant introductions from Asia or plant selections from those introductions (Hymowitz et al., 1977). Active soybean breeding increased after 1945. Between 1946 and 1970, 110 cultivars were released from public plant breeding projects (Table 5-1). With the passage of the Plant Variety Protection Act in 1970, private soybean breeding increased. Between 1970 and 1983, a total of 247 soybean cultivars were released under plant variety protection (Asgrow Seed Company, 1983). Most of these were developed by private soybean breeding projects. Sixty-four public cultivars in maturity gorups 00 to IV were released between 1971 and 1981 (St. Martin and Bernard, 1982). In maturity groups V to VIII, 93 public cultivars were released (Hartwig, 1987). As the number of public varieties has increased, the number of acres planted with private cultivars has also increased. There are currently 57 private cultivars available to farmers in North Carolina versus 23 public cultivars (Dunphy, 1987a). In North Carolina, the acreage planted to public cultivars has decreased from 81.4% to 62.7% in the past 4 years (Dunphy, 1987b). The trend toward increased use of private cultivars will probably continue due to the release of improved private cultivars and the ability of private companies to effectively market their cultivars.

Procedures for Release

Most soybean cultivars are the inbred progeny from matings between two or three inbred lines or cultivars. They are usually "pure" lines which means they have a high level of genetic homozygosity from having been inbred through at least three generations of self-pollination. A soybean breeder selects the "best" inbred lines from among several populations of lines. These lines are tested in local and regional tests before a decision is made to recommend the line for release as a cultivar. This decision is made based on its yielding ability relative to currently grown cultivars in the same maturity grouping as the line under consideration for release. Decision to release is also based on other traits which contribute to agronomic quality and yield stability over a range of environments. These traits include resistance to plant lodging, disease and pest resistance, stress tolerance, and seed quality.

Every state experiment station or private seed company has a committee that reviews and approves prospective cultivar releases. A soybean breeder who has selected a line that is suitable for release as a cultivar must prepare a report or "defense" of the line. This includes a summary of pertinent test data and a statement which gives a rationale for release. The latter explains the unique characteristics of the line which would make it an important addition to the cultivars available to farmers. Productivity and usefulness to growers (and consumers in some cases) are the primary criteria in releasing new varieties. For private plant breeding companies, stability is also a very critical consideration in the release of a new cultivar (Brim, 1987). Because a company's name and reputation is associated with the cultivars they release, the company cannot afford to release a cultivar which performs poorly in some environments.

Every state has its own cultivar release policies, however, these policies have all been developed within the guidelines of USDA policy (USDA, 1972) and federal law (Federal Seed Act of 1939 and Plant Variety Protection Act of 1970). As an example the North Carolina Agricultural Research Service (NCARS), makes the following statement in its Plant Patent and Plant Variety Protection Policy and Procedure Statement: "New plant cultivars and breeding lines may be released for public use if judged to be either unique or superior to currently available germplasm, or equal to presently available cultivars if the genetic base of a crop is broadened so as to reduce disease and other pest hazards" (NCARS, 1981). This policy statement in its entirety explains NCARS policy on patenting plant materials, exchange of germplasm with other institutions, granting exclusive rights to plant materials, and leviing royalties and liscense fees. In general, the germplasm release policies and procedures of NCARS and other state agricultural experiment stations are compatible with those of the USDA-ARS. Differences may exist when restricted releases occur.

USDA-ARS releases or participates with states in the release of germplasm when ARS is the developer or co-developer. This requires the ARS scientist to be lead breeder or to be in continuing cooperation with a state lead breeder with germplasm release as a research object (Miller, 1985). Both USDA-ARS and state AESs generally release germplasm on an unrestricted basis. USDA-ARS can collect royalties on a solely owned variety, but ARS generally deems this impractical (USDA-ARS, 1982).

Tests Conducted/New Tests Needed

Most soybean cultivars are released after a series of tests which are conducted locally at first (in a geographical area assigned to a specific breeder) by the breeder of the cultivar, and then regionally in a cooperative testing program with other soybean breeders. This procedure is true of both public and private soybean breeding programs. The cooperative regional tests conducted by USDA-ARS in cooperation with state agricultural experiment stations will serve as an example. These tests were begun in 1945. Because they were the first of their kind in soybean breeding, they have served as a model for other regional testing programs established by private seed companies. The regional tests are primarily tests of yielding ability, however, an array of other traits are noted for each entry in a test. A description of this testing program follows.

After a line is tested locally, a public breeder enters the line in the regional preliminary trials. There is a different trial for each maturity group. If the line is in maturity groups 0 - IV it is entered in the northern regional preliminary which is coordinated by Dr. J. R. Wilcox (research geneticist, USDA-ARS, at Purdue University). If the line is in maturity groups late IV to VIII it is entered in the southern regional preliminary which is coordinated by Dr. E. E. Hartwig (research geneticist, USDA-ARS, Stoneville, Mississippi). These are two replicate tests that are usually conducted at between six and nine locations in as many states. In the southern tests the following traits for each are noted and published in the test results: seed yield, maturity index, plant height, oil and protein percentage, resistance to M. cognita, races 3 and 4 of cyst nematode, soybean looper and stem canker (Hartwig and Edwards, 1986). In the northern tests the following traits are noted and published: yield, maturity index, plant height, seed quality, seed size, percentage oil and protein and resistance to shattering, iron chlorosis, brown stem rot, phytophthora rot, purple stain, pod and stem blight, and soybean mosaic virus (Wilcox, 1986). Those lines which perform the best and/or have a unique characteristic that warrents further study are entered in the Northern or Southern Uniform Tests the following year. These are three replicate tests which are conducted at between 14 and 30 locations in several states depending on the adaptation area for the maturity group. In the Southern Uniform tests, the following traits are noted: seed yield; oil and protein percentage; lodging, seed size; maturity index; plant height; seed quality; and resistance to M. incognita, M. arenaria, races 3 and 4 of cyst nematode, soybean looper and stem canker. In the Northern Uniform tests the first eight of the above traits are noted and in addition the following are noted: emergence; tendency to shatter; resistance to iron chlorosis, brown stem rot, bacterial tan spot, phytophthora rot, purple stain, pod and stem blight, and soybean mosaic virus.

New tests are added within the existing program if a particular trait becomes economically important. For instance, after 1982 when the occurrence of stem canker was widespread in the southern states, test locations where stem canker was known to be a problem were added to the uniform Group V, VI, VII and VIII tests. Other disease responses are noted from time to time as they occur at test sites. The USDA regional testing program is flexible in this regard and any new trait that needs to be evaluated in lines under scrutiny for possible release as cultivars can be accommodated in the existing program.

Criteria for Tests

The primary object of plant breeding is plant improvement through genetic alteration. A new cultivar should be improved and thus genetically and phenotypically different from other varieties. For a new cultivar to be eligible for plant variety protection, it must be clearly distinct from all other varieties (Batcha and Studebaker, 1983). In this light, a primary criteria for a test is its ability to establish differences and similarities among breeding lines and cultivars. This is not for the purpose of simply knowing that they are different. Rather by knowing the differences and similarities, appropriate decisions can be made about where and when a cultivar should be grown, the suitability of a line for release as a cultivar, and performance expectations for a cultivar in any given environment.

Tests are needed which characterize a cultivar or breeding line with respect to particular traits. For instance, if a farmer has a known pest problem such as a cyst nematode in a field, then it is crucial for him to know whether or not a cultivar is resistant to cyst nematode infection and reproduction. The productivity of a cultivar relative to other cultivars is another trait that a farmer needs to know when making a decision about which cultivar to plant. This would apply to any trait which would make an economic difference to a farmer.

Length of Time for Approval

In North Carolina, the release of a new public soybean cultivar is approved by the Director of NCARS based on recommendations of the SALS Breeders Release Board (NCARS, 1981). For a cultivar that is developed with classical plant breeding methods, approval by the Director usually takes only as long as it takes the Breeders Release Board's decision to reach his attention. This is usually less than four weeks. This is typical of other state agricultural experiment stations. If USDA-ARS has participated significantly in the development of the cultivar, then approval to release must also be obtained by the Administrator of USDA-ARS (USDA-ARS, 1972). Again, this approval can be obtained in a relatively short period of time (four to six weeks). Sometimes other state agricultural experiment stations participate in the release of a soybean cultivar, in which case the approval and signature of the Director of each of the participating SAEs is needed. This is usually very forthcoming because the experiment station director sees his role as one of trying to make release of a cultivar as expeditious as possible (Johnson, 1987). The time required to obtain approval is usually only a few weeks. For soybeans, this approval system has worked well and is unlikely to change.

For a private cultivar, a seed company decides to release a cultivar upon recommendation by a committee of other soybean breeders in the company in consultation with the company's director of research. As previously discussed, this decision is often made by a review of test data that shows the new cultivar is sufficiently productive and stable (Brim, 1987). The final recommendation and approval to release is usually obtained from a committee of company managers which includes marketing, production and research personnel.

If a soybean cultivar were developed using non-classical genetic engineering methodology, approval for release could take longer. Currently, testing of such genetically engineered plants is regulated by the U.S. Department of Agriculture with the advice of its Recombinant DNA Research Committee. Because these kinds of plant varieties are only in the developmental stages, not much is known about how they will be regulated (Sun, 1986a). It is unlikely that genetically engineered plants will be regulated as closely as microorganisms. However, the recent difficulties in obtaining approval to test the genetically engineered _Psuedomonas syringae_ and _P_. _flourescens_ bacteria (Sun, 1986b) illustrate the kinds of delays which could occur in trying to gain approval for the release of a genetically engineered cultivar.

Length of Time for Development and Release

In a survey of sixty-four Plant Variety Protection applications for soybean cultivars, the average time required from cross to application was 9.2 years (Asgrow Seed Company, 1983). This time for development and release would be similar for both private and public cultivars. The use of a winter nursery in the inbreeding stages can shorten the time between making a cross and the development of a pureline that has variety potential (Fehr, 1976). However, this has become a common practice of all soybean breeders, so that the 9.2 year estimate would include the time savings involved in winter nursery use.

New biotechnologies are unlikely to significantly reduce the time for development and release of a cultivar. Of the nine years required to develop a variety by classical methods, six or seven are used in testing the cultivar under farm conditions and in seed increase. It is doubtful that biotechnology could eliminate the need for the testing period (Hansen et al., 1986). Therefore, time saving would have to take place in the two or three years prior to testing. In Nicotiana, it is possible to produce inbred lines by diploidizing maternally or paternally derived haploids (Burk et al., 1972; Burk et al., 1979). In this case it is possible to produce a pure line in one year. If this or some other technique could be used in soybean, the time for cultivar development could be reduced from 9 to 8 years. Because of generation time (Ca 4 months) and the low seed set on single soybean plants which make seed increase seasons necessary, it is doubtful that more than 1 year could be subtracted from the current time required for soybean development.

Effect of Patenting and Licensing

There are three ways to protect plants as intellectual property — a plant patent, plant variety protection, and a utility patent. The plant patent applies only to asexually reproduced varieties and therefore would not apply to soybeans. Conditions for a utility patent require that the genetic change in the plant be new, useful and unobvious (the characteristics of the new plant must be unobvious over what is known as to that type of plant). The utility patent would be used in cases where genetic changes were obtained in a plant by other than classical plant breeding methods. This would apply to the introduction of a foreign gene into a plant by nonsexual means (biotechnology). It is difficult to predict what effect these utility patents will have on soybean cultivar development. However, obtaining a utility patent is likely to be much more expensive and time consuming than obtaining a PVP certificate because of the difficulties involved in proving that the cultivar meets patent conditions. Obtaining patents on other technologies can require from one and a half to two years and it is unlikely that this utility patent will require less time (Johnson, 1987). As visualized by some companies involved in genetic engineering, once the gene or genes introduced into a cultivar are patented, the company will have exclusive right to their use in other cultivars (Johnson, 1987). This will certainly restrict the use of genetically engineered germplasm and make cultivars that carry the genes more expensive.

Plant Variety Protection is the most common method of "patenting" a cultivar. Between 1970 and 1983, 247 soybean cultivars received PVP certificates. The PVP certificate prevents others from growing and selling seed of a protected cultivar without the permission of the variety owners. The conditions for protection are that the cultivar must be clearly distinct from other varieties, sexually reproducing while retaining its distinct and essential characteristics, and varients are describable, predictable and commercially acceptable (Batcha and Studebaker, 1983).

Concerns about PVP influence on cultivar development has centered around the economic concentration in the seed industry and the loss of genetic variability (Claffey, 1981). In the case of soybean, neither of these has occurred. After 1970, the number of seed companies breeding soybeans increased from 6 to 28 (Batcha and Studebaker, 1983) which would appear to be a movement away from economic concentration. The fact that more cultivars have been released as a result of private industry is some evidence that genetic diversity has at least not decreased. Also, publicly released germplasm is heavily requested and used when needed by private seed companies. Another healthy characteristic of soybean breeding in general is the free exchange of released germplasm and the free use of any released cultivar as a breeding parent. Soybean breeders, both public and private, meet together each year at a soybean breeders workshop. The relationship between both groups is amicable and research results are freely shared.

Summary

The increase in private soybean breeding which resulted from the Plant Variety Protection Act of 1970 has been a positive development. The agronomic quality of both public and private soybean cultivars has increased. There is a continuing need for public soybean breeders to engage in basic plant breeding research and germplasm enhancement. Because private soybean breeders single-mindedly pursue seed yield and yield stability as a goal, they are highly dependent upon public research to provide new germplasm resources and breeding methodology.

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Table 5-1. The number of soybean cultivars released by public institutions in the United States and Canada prior to 1976 (Hymowitz et al., 1977).

Maturity Groups	Prior to 1946	1946 - 1970	1971 - 1976	Total
00 - I	35	29	8	72
II - IV	98	54	12	164
V - VII	43	22	6	71
VIII - X	18	5	4	27
TOTAL	194	110	30	334

Table 5-2. The private companies that develop soybean cultivars and the numbers of cultivars they released between April 1973 and November 1987 which received plant variety protection (PVP) certificates.

Company	No. of PVP Cultivars not under Title V	No. of Title V PVP Cultivars
Agratech Seeds		1
Agripro, Inc.	7	
Americana Seeds, Inc.	1	
Asgrow Seed Company	48	
B.B. Collier-Barney A. Smith		1
Bryco Plant Res. Division	1	1
BSF/Ag Research	1	
Callahan	6	1
Coker's Pedigreed Seed Co.	22	16
Dairyland Seed Co., Inc.	3	8
Delta and Pine Land Co.	7	1
Ferry-Morse Seed Co.	1	
FFR Cooperative	8	1
Funks Seeds		1
Goldkist		1
Growmark, Inc.	1	
Helena Chemical Co.	5	
Identity Seed & Grain Co.	1	
Illinois Foundation Seed		1
Jacob Hartz	9	3
Jacques Seed Co.	8	
J.M. Schuetz Seed Co.	1	
King Grain U.S.A., Inc.	4	

Table 5-2. (Continued)

Company	No. of PVP Cultivars not under Title V	No. of Title V PVP Cultivars
Land O'Lakes, Inc.	11	
Louis Bellatti		2
Lynnville Seed Co.	4	1
Midwest Oilseeds, Inc.	4	
Milburn Farms		1
Nickerson American Plant Breeders	6	
Nixon Seed Co. & L.		1
North American Plant Breeders	26	
Northrup King Co.	24	15
Pioneer Hi-Bred International, Inc.	40	1
Prarie Seed Co., Inc.	1	
Scientific Seed Co., Inc.	1	
Soybean Res. Foundation, Inc.	13	20
Stanford Seed Co.		1
Syler	1	
Terral-Norris Seed Co., Inc.		7
Teweles Seed Co.	4	
Voris Seeds, Inc.	1	
V.R. Seeds, Inc.	8	
Totals	278	85

CHAPTER 6

Plant Breeding Technology

Adequacy of Germplasm Base

There are over 10,000 accessions of soybean (Glycine max) and other Glycine species in the germplasm collections which are maintained by USDA-ARS at Stoneville, MS (Maturity Groups V to X) and Urbana, IL (Maturity Groups 000-IV). Genetic variation exists in this collection for most of the seed quality traits considered in Chapter 1 of this paper. Genes for resistance to many of the diseases have been discovered and there is a wide range of variants for most quantitatively inherited traits.

With respect to physical seed quality, seed size was the only trait identified as a possible quality factor. In USDA soybean germplasm collections of Maturity Groups V to X, seed size ranges between 4.0 and 44.0 gm/100 seeds (Hartwig and Edwards, 1975 and 1980). Smaller seed sizes can be found in the wild soybean (G. soja) collection.

There is some genetic resistance to fungal diseases which affect biological quality of seeds. Plant introductions (PIs) in groups II, III and IV were evaluated for resistance to Phomopsis-Diaporthe complex of fungi which cause moldy seed. Nine of these PIs had consistantly good seed quality and are currently being used in soybean breeding projects aimed at improving seed quality (Buss, 1983). Improved germplasm with resistance to Phomopsis has also been released for general use by soybean breeders (Ross, 1986). Resistance to purple seed stain caused by Cercospora bibuchii (T. Matsu and Tomayasu) Gardner has been found in 25 accessions of the soybean germplasm collection (AVRDC, 1979). There is also evidence that the hard seed coat trait can be useful in preventing seed disease and loss of seed viability (Hartwig and Potts, 1987).

Two gene loci have been found that condition resistance to soybean mosaic virus (SMV) which causes seed mottling. Two alleles at one locus, Rsv and vst-t, give resistance to two SMV strains (Kiihl and Hartwig, 1979) and a single allele at a second locus (RSC2) confers resistance to a third SMV strain (Buzzel and Tu, 1984).

Post harvest deterioration of seed in storage is probably not as much a function of the seed genotype as it is a function of the condition of the seed when they are put into the storage facility. However, some lines have been identified that seem to have superior longevity in storage (Kueneman, 1983). The genetic trait for seed longevity has been incorporated into three agronomically improved breeding lines which have been recommended for use in cultivar development (Kueneman, 1985).

Some seed quality problems arise as a result of pod feeding by stinkbug (Nezara viridula). Some apparent genetic resistance to stinkbug does exist (Jones and Sullivan, 1979), however, no stinkbug resistant cultivars have been developed and released. Because stinkbug infestation and damage is sporadic across years and locations, breeding for resistance to the insect has been a very low priority in the soybean breeding projects that have dealt with it at all. The extent of insect damage is difficult to measure, which makes it a very troublesome trait to work with. Research on host-plant resistance to stinkbug is not likely to increase unless reliable laboratory methods are developed which make it easier to screen genotypes for resistance.

A significant quantity of genetic resources are available for use in changing oil and protein percentage. There is a wide range (approximately 15%) in percentage protein among lines of the United States soybean germplasm collection. About 10% of the lines have a protein percentage higher than 44.5% (Hartwig, 1979). The wild species, G. soja, with a protein content that is typically greater than 45% also has been used as a source of high protein germplasm (Erickson et al., 1981). Two high protein populations, NC-1 and NC-2, that were developed through recurrent selection have been released as germplasm (Burton and Brim, 1983; Burton, et al., 1986). The United States soybean germplasm collection also contains lines with wide variation in oil percentage. For example, the Group I, II, III and IV accessions obtained prior to 1970 range from a low of 13.2% to 23.5% (U.S. Regional Soybean Laboratory, 1966, 1969). Selection for increased percent oil is possible using standard plant breeding methods (Burton and Brim, 1981), however no germplasm has been released with seed oil percentage greater than 23.5%. Two cultivars, Amsoy and Ransom, with higher than average oil (22 to 23%) have been released and widely grown because of their high yielding ability (Weber, 1966; Brim and Elledge, 1973).

The difficulty in breeding for seed oil and protein in soybean is that there is a high negative genetic correlation between the two traits. An increase in one usually leads to a decline in the other (Brim and Burton, 1978; Burton and Brim, 1981). Two exceptions to this have been reported. Simpson and Wilcox (1983) found a negative genetic correlation of one -0.15 in a population derived from mating an unadapted high protein line with an adapted average protein line. In another study, Openshaw and Hadley (1983) found that selection for increased oil plus protein resulted in a 0.3% increase in protein and a 0.4% increase in oil. Thus, increasing both oil and protein simultaneously might be possible within very narrow limits using standard plant breeding methods and the appropriate plant population. A more general solution to the problem of increasing both protein and oil in soybean seeds will probably require a novel technique. More knowledge about the physiological linkage between oil and protein synthesis in seeds is needed. This problem will probably not be resolved in the foreseeable future.

Percent seed oil and percent seed protein are also often negatively associated with seed yield. However, the correlations are generally lower and positive genetic correlations between yield and either oil or protein have been reported (Burton, 1987). Progress in increasing both seed protein and yield using standard plant breeding practices has been reported (Hartwig and Hinson, 1972; Holbrook, 1985; Sebern and Lambert, 1984; Wehrmann et al., 1987). Similar progress in selection for higher yield and higher oil should be possible.

Present Technology

Soybean cultivars are typically developed by hybridization of two or more lines followed by self-fertilization to the F_4 or later generation. Homozygous lines (purelines) are isolated and tested to determine those with superior performance and cultivar potential. With this method, the major issue has been how material in the F_2, F_3 and F_4 segregating generations should be handled. The method used depends upon the plant breeding objectives and personal preferences of individual soybean breeders. Pedigree selection or modified pedigree selection (Brim, 1966) are the most common methods for systematic inbreeding (Fehr, 1987). Backcross breeding is commonly used for transferring a few gene loci from a low yielding line to a high yielding cultivar. Modification of those standard practices include population improvement through early generation testing and recurrent selection, bulk breeding and mass selection.

The other issue which is very important and which has received a lot of attention is what is the most appropriate and efficient way to evaluate lines with respect to a particular trait. Various field plot and laboratory testing techniques have been developed and used (Fehr, 1987). The appropriateness of a particular technique depends on the trait being evaluated and the ease with which it is measured. Much of the success or failure of a particular breeding project can be attributed to the quality of the genotypic evaluation program.

These classical methods are adequate for the transfer and recombination of genes within the species and have been successfully used to improve soybean cultivars. Higher yielding cultivars with disease and pest resistance have been developed and released over the past 40 years. Progress, while continuous throughout this period, has been slow. The rate of increase in seed yield has been estimated at between 0.6 and 1.0% per year (Wilcox et al., 1979; Leudders, 1977; Boerma, 1977). It is likely that for at least the next ten years the classical methods, because they are in place and successful, will continue to be those most used to produce improved cultivars.

It is currently not possible to economically produce the seeds for F_1 soybean hybrids. Patents for two F_1 hybrid seed production methods have been issued. (Bradner, 1974; Davis, 1987). However, it remains to be demonstrated that either can be used to economically produce hybrid seed. Good evidence for significant hybrid vigor in the soybean species is limited (Burton, 1987). As a result, very little research is being conducted on F_1 hybrid seed production for soybeans.

Future Technology

Future technology in the genetic alteration of soybean will undoubtedly include recombinant DNA methods or as these methods are popularly referred to — genetic engineering. Genetic engineering includes many different techniques, but in plants the ultimate goal of all of them is the placement of a foreign gene or genes into a cultural plant cell, followed by regeneration of a whole plant from the cell in which the foreign gene is expressed.

Some progress is being made in the regeneration of whole, fertile plants from soybean tissue and cells in culture (Christianson et al., 1983; Gamborg et al., 1983; Lazzeri et al., 1986; Ranch et al., 1986; and Meyers et al., 1986), however, it is impossible to predict how long it will be before regeneration becomes a routine procedure. Various methods for transferring genes into plants are being developed and plant transformations have been successful. For instance, a gene which imparts tolerance to glyphosate herbicide has been introduced into Petunia (Shah et al., 1986).

If methods for foreign gene transfer and regeneration are developed for soybean, there will still remain the problem of isolating genes, determining which genes can be beneficially introduced into a plant, and regulating the gene expression once it is introduced. In soybean, the traits which are most likely to be altered through genetic engineering are seed protein and oil quality, plant stress tolerance, pest and disease resistance and herbicide tolerance (Goodman and Kiser, 1985). It is expected that desirable changes in these traits can be obtained by manipulation of a very few genes. As of now, not many soybean genes have been cloned, sequenced, and the gene product isolated. More basic genetic information is needed about plant traits in order to make significant changes in soybean through genetic engineering (Goodman and Kiser, 1985).

Only the seed quality traits that are related to disease reaction, such as the mottling caused by soybean mosaic virus, are likely to be affected by new genetic engineering technologies in the near future. Percent seed protein and oil and seed size, like seed yield, are polygeneic. Many unidentified genes are involved in the determination of these traits. This makes them very difficult to evaluate at the cellular level and to work with at a molecular level (Hansen et al., 1986).

The new molecular genetic technologies hold great promise and much important biological information will be learned from molecular genetic research. This will eventually trans-late into practical ways to genetically alter plants in a desirable way. However, in the short term, most improvement in soybean seed quality will come through classical plant breeding. As G. F. Sprague (1980) has observed: "The molecular biologist is encouraged and increasingly optimistic with each success in protoplants fusion or demonstration of successful selection in suspension cell culture. The plant breeder recognizes the many criteria which much be satisfied to obtain a new commercially acceptable cultivar. He may be intensely interested in future possibilities arising from genetic engineering but feels there is little in the current state of the 'genetic engineering art' that is immediately useful to him. The molecular biologist is enthused over progress made and the plant breeder is awed by the problems remaining to be solved before genetic engineering can become a routinely useful tool."

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Background Paper No. 3

Grain Quality and Corn Breeding

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KERNEL QUALITY AND CORN BREEDING

Quality defined

In the United States, corn is sold as grades No.2, No.3, No.4, No.5, and Sample Grade (Table 1). Grade No.1 is defined but not paid for at the market. Lower grade number signifies higher quality corn. Sample grade is poorer grade than No.5. Foreign odor is a cause for Sample Grade regardless of other grade criteria. Better grades have heavier test weight, less foreign material, and fewer broken and damaged kernels (Table 1). Broken kernels pass through a 12/64" sieve and over a 6/64" sieve. Foreign material is all matter that passes through a 6/64" sieve and matter other than corn that remains on a 12/64" sieve. Test weight is a measure of bulk density (weight/volume). Moisture is no longer used as a grade factor. Corn is divided into three color classes: Yellow, White, and Mixed based on kernel color.

Although kernel quality can be reduced by a number of ear-rotting diseases, ear rots have not caused severe losses over extensive areas (Ullstrup, 1977). Diplodia and Gibberella ear rots are more likely to happen in years with much rain in the fall. Hybrids that hold the ear upright may catch and hold water in the husks and increase rotting. Fusarium kernel rot is more prevalent under drier conditions and is often associated with earworm and corn borer damage. Kernel rotting is genetically controlled and may be affected by the chemical composition of the kernel; sweet corn and high lysine corn are more susceptible to attack (Ullstrup, 1971, 1977).

Kernel quality is also reduced by premature plant death that reduces kernel size and test weight. Leaf blight and stalk rot diseases commonly cause premature death and reduce both yield and kernel quality. Corn breeders routinely challenge breeding materials with these diseases to select for resistance. Stay-green is the opposite of premature death and can be effectively selected for (Troyer, 1978). Early frosts can also cause premature death and reduced grain quality particularly in the northern Corn Belt.

Kernel quality may also be regarded in terms other than grain grading standards. Seed for planting is measured by warm test germination and by cold test germination to predict probable germination and stand attainment in farmers' fields. Also, quality is used in a general sense, particularly in the South, to indicate smoother, harder textured ears that generally have higher test weight and freedom from disease and insect damage.

Corn chemical composition is about 72% starch, 10% protein, 5% lipid, 2% sugar, and 1.4% ash on a moisture-free basis (Inglett, 1970). Historically corn has been a source of inexpensive starch used primarily for animal feeds. A secondary but increasing market uses corn as a raw material for industrial processes.

Historical selection traits

Corn breeding is accomplished by selection for desired plant traits both during inbred development and during hybrid evaluation. Corn breeders have always selected for traits that give higher yield and easier harvest with the current cultural practices of the period. Harvest method has been the most important cultural practice that has influenced selection traits for corn.

During the hand-harvest period (pre-1940), popular open-pollinated varieties grew quite tall; plant population densities were low, so larger plants were higher yielding. Stalk strength and ear retention were of little economic importance because fields were fenced and livestock were used to glean ears. Grain texture (determined by type of starch) was quite soft; Reid Yellow Dent, a very soft corn, was grown on 75% of the Corn Belt acreage for more than 50 years. During this era, more than 90% of the corn was fed on the farm; soft-starch corn was easily consumed and digested by livestock. Ease of shelling was of little concern. Breeders selected for large single-eared plants to make hand-husking easier. Root strength was less of a problem then than now because crop rotations slowed rootworm build-up. In general, farmers grew late varieties relative to a given latitude; fodder shocks encouraged the use of late corns because the beginning of ear corn drying was forced at the time of cutting.

Hybrid corn made mechanical pickers possible because of better standability. The corn-picker-harvest period (1940 to 1960) saw many corn production improvements: More fertilizer, higher plant densities, more continuous corn, better herbicides and insecticides, cheaper nitrogen, and earlier planting were some of the more important. Cold tests and other indicators of seed vigor were devised by breeders to develop corns adapted to earlier planting. Plant and ear height were unaffected by use of corn pickers. Most farms were still diversified, and livestock consumed much of the corn on the farm where it was grown. Breeders selected corns for not shelling too easily on snapping rolls and on husking beds of corn pickers. Continuous corn led to rootworm build-up and strains of insecticide-resistant insects, so stronger rooted hybrids were needed. Farmers preferred hybrids that picked cleanly and easily, so breeders selected for smaller shank-to-ear attachment (Baker, 1955). Use of higher plant densities required selection by breeders of corn genotypes that tolerate stress due to plant crowding. About the same maturity corns were still being grown in a given area (generally full season) and test weight still wasn't a problem because corn sold off the farm was naturally-dried ear corn.

The field-shelling-harvest period (1960 to present) has brought larger farms, still higher plant densities and fertilizer rates, even more continuous corn, and more corn marketed off the farm (Troyer and Rosenbrook, 1983). Artificial driers became commonplace throughout the Corn Belt. For a time, large farms and small equipment increased the need for better standing corns; then, newer combines and other equipment steadily increased operational capacity. Tax investment credit helped re-equip Corn Belt farms. Corn became shorter and lower eared in this period as farmers shifted to earlier corns in order to start combining sooner. Today's corn probably averages a foot shorter than that grown before 1960. Before the invention of quick-attach heads for combines, stalk quality became extremely important to large operators in cash-grain operations because corn harvest often waited until soybean harvest was finished. Ear retention was also very important to these operators; cash-grain meant fewer fences, so fields could not be gleaned by livestock. Harder starch, or flintier types, allowed earlier start of harvest by reducing the number of broken kernels resulting from high moisture shelling. Artificial drying of corn, which lowers test weight, coupled with more direct selling from the field with test weight discounts, further increased the need for harder textured, flintier corns. Hybrids with stronger cobs and easier shelling became an advantage for combine harvest. As the cost of fuel went up, corn hybrids that dried faster, both in the field and in the drier, became more desirable (Troyer and Ambrose, 1971). Genetic selection for tolerance to higher plant densities reduced barrenness and increased the frequency of two-eared plants. Adoption of minimum tillage, to reduce expenses, increased incidence of diseases and insects (gray leaf spot, corn borer, etc.) resulting in more breeding emphasis on these problems.

Corn breeding has been extremely effective. Since the introduction of hybrid corn, the U.S. average corn yield has increased steadily from 16 bushels per acre in 1936 to 110 bushels per acre average for 1981 through 1987. Since single cross hybrids (ca. 1960), the average yield increase per year is 1.89 bushels (Fig. 1). Most of this yield increase is genetic improvement. Three investigations (Russell 1974, Duvick 1977, and Castleberry et al. 1984) compared yields of hybrids from various eras; the gain in hybrid performance due to breeding averaged 64% of the total gain in annual corn yields (Table 2). The other 36% has been attributed to improved cultural practices such as fertility, weed control, plant density, planting date, row width, etc. Corn breeders have successfully matched breeding objectives with improved cultural practices to steadily and rapidly increase national average yields of corn and will continue to do so in the future (Troyer and Rosenbrook, 1983).

The future will bring fewer farmers, but because of more specialization there will be more large cash-grain farms. Average corn yields will continue to increase. Plant densities will continue to increase, but at a slower rate, perhaps 1% per year. Although fertilizer rates will remain high, not as many super-high nitrogen rates will be used as before. Energy costs will correlate negatively with fertilizer rate, with plant density, with amount of tillage, and with maturity of corn grown. The price of seed, along with the price of everything else, will probably continue to increase. Earlier corns (5 days earlier than present, 10 to 15 days earlier than pre-combine times) will be used in areas north of the 40th parallel (Springfield, Indianapolis, Columbus, Philadelphia) to reduce drying cost. Drying costs do not influence the maturity of corn hybrids grown south of the 40th parallel because of ample field-drying time between maturity and harvest. Average ear size, in the Corn Belt at least, will continue to decrease as stress resistant, more prolific corns are developed. More governmental regulations to protect the environment will require increased breeding emphasis for tolerance to disease and insects; this will slow, but not stop, breeding emphasis for yield per se. Grain will continue to become flintier to help reduce mechanical damage to the kernels and enhance the quality of the crop for export market. There will be more use of specialty corns--waxy corn for industrial purposes, early corns used for double cropping, etc. It's possible, though not likely, that a breakthrough for stalk quality in corn could occur (like dwarf wheat). It could come by use of dwarfing genes, by hard rind stalks, or by a new fungicide; this would allow more breeding emphasis for yield. However, it's more likely that stalk quality will continue to be an important selection trait.

Many states have performance trials that compare hybrids. Farmers often try the winners of these trials. State experiment stations can also affect genetic selection through livestock feeding trials. In the 1920's, dry-lot trials of swine showed an advantage for yellow over white endosperm (vitamin A); more emphasis on breeding and more use of yellow corn followed. Similar, more recent, trials on high lysine and waxy corn have stirred breeding interest in these endosperm mutants.

Future genetic selection due to new corn markets

About 300 million bushels of corn are used annually to produce ethanol to blend with gasoline. Ethanol is an economical replacement for lead as an octane booster. Lead endangers the environment and is being legislated out of fuels. Ethanol-enhanced gasoline currently accounts for about 6% of total gasoline sales in the U.S. (Anon. 1987). The use of ethanol as a gasoline substitute depends on the cost ratio of corn to crude oil. Corn has the advantage of being a renewable resource. Ethanol for fuel should serve as a floor for market price of corn. With additional yield increases that lower production cost per bushel or with higher oil costs, large amounts of corn can be used for fuel as a substitute for petroleum. Average annual U.S. corn production (7.5 billion bushels) would supply only 13% replacement for gasoline or 26% replacement for diesel fuel on an energy equivalent basis (Goering, 1987). Ethanol can also be used to clean sulfur from coal to produce higher grade coal that creates less pollution. Desulfurization for midwestern states coal production could utilize a billion bushels of corn per year (Anon. 1987). The selection needed would be higher yields that lower cost per unit of corn.

About 530 million bushels of corn are used annually to produce High Fructose Corn Syrup (Anon. 1987). Concentrated HFCS lowers calories when used as a sucrose substitute in diet foods. Most HFCS is used in soft drinks, but it is also used in the baking and canning industry as a sucrose substitute. Corn starch is used exclusively in the United States as raw material for starch-based sweeteners because of its favorable cost (Hebeda, 1987). Again, selection needed by corn breeders is to lower the cost per unit of corn through higher yields. Endosperm type may also affect HFCS production costs.

Additional newer specialty uses for corn include the development of a non-corrosive salt substitute to melt ice on roads that could use 60 million bushels of corn annually (Anon. 1987). Corn starch can also be used to produce biodegradable plastic containers and plastic sheet films. It can also be used as an absorbent. Again, these uses depend on low cost corn starch.

Kernel quality attributes under genetic control

As mentioned earlier, Reid Yellow Dent was widely grown in the Corn Belt for 50 years. Many substrains were developed, and many inbred lines have been developed from this background. The origin of Reid Yellow Dent is well documented (Wallace and Brown, 1956). It resulted from the cross of a late southern dent type that had soft, long kernels of gourdseed or semi-gourdseed shape with an early northern flint type that had smaller, harder kernels. The northern flint races have 8 to 10 rows of crescent shaped kernels that have a high proportion of horny or vitreous starch; the southern dent races range from 8 to 26 rows of long or deep kernels that have a high proportion of soft starch (Brown and Goodman, 1977). The Reids, father and son, selected for an intermediate type that in most ways resembles the corn of today in the U.S. Corn Belt.

Genetic studies of corn have identified 600 to 1,000 simply inherited traits; factors are known that affect aleurone tissue, starchy portion of the endosperm, and pericarp of the kernel as well as husks, ovules, silks, and cobs of the ear (Coe and Neuffer, 1977). The endosperm is triploid (2/3 maternal, 1/3 paternal), so dosage effects occur for dent versus flint and for yellow versus white. A direct relationship occurs between vitamin A and number of genes for yellow pigmentation (Mangelsdorf and Fraps, 1931).

Genetic selection for chemical composition has been very effective in the long-term selection experiments begun at Illinois in 1896 (Dudley et al., 1974). Protein percentage in the original Burr White variety was 10.9%. After 70 generations of selection, Illinois High Protein was 26.6% and Illinois Low Protein was 4.4%. Oil percentage in the original Burr White variety was 4.7%. After 70 generations of selection, Illinois High Oil was 16.6% and Illinois Low

Oil was 0.4%. Numerous single gene mutants such as waxy, dull, sugary, amylose extender, shrunken, brittle, and others have been found that affect carbohydrate composition (Alexander, et al., 1970). The opaque-2 single gene mutant doubles the percentage of lysine and tryptophan in the endosperm by reducing the synthesis of low-quality zein proteins (Mertz, et al., 1964). Much breeding was done to incorporate this gene into widely used inbred lines and several commercial hybrids were sold. Unfortunately opaque-2 hybrids typically have yielded less than normal counterparts and have dull appearance of the grain, slow drying, and increased vulnerability to kernel pests and rots.

Corn yield versus kernel quality

Corn is a source of inexpensive starch. The ability to change corn's end use to a source of protein or oil in the future, depends on the relationship of yield to chemical composition during selection. Dr. John Dudley, University of Illinois, found genetic correlations between yield and protein ranged from -0.41 to +0.34 and averaged -0.06 over eleven years of half-sib selection in stiff stalk synthetic indicating yield and protein can be increased simultaneously at average yield and at average percent protein levels—perhaps up to the 14-18 percent protein range (Dudley, 1988). Analysis of crosses among extremes of chemical composition showed correlations of -0.70* for yield versus percent protein and of -0.49* for yield versus percent oil suggesting that production of maximum protein or oil per acre could best be achieved with intermediate levels of protein and oil coupled with higher yields per acre (Dudley, etal. 1977).

Higher yields in corn over the decades have resulted, to a considerable extent, from replacing low yielding, high grain quality, flint (hard) endosperm types with higher yielding, lower grain quality, dent (soft) endosperm types. In the late 1800's, Reid Yellow Dent spread from central Illinois throughout the Corn Belt. In the 1930's, dents spread northward with hybrid corn, and to this day, continue to push the Corn Belt even farther northward. Since 1970 dents have also increased in use in the South, as Corn Belt-type hybrids replaced later, more flinty, native types. At present the same trend is occurring in Europe and South America. Flint endosperm corn not only yields less but also dries slower both in the field and in the grain drier. Farmers prefer the higher yield and faster drydown of softer textured corn to increase their net profit. For these reasons the most popular hybrids have near average test weight and dent kernels rather than high test weight from flint kernels.

Pericarp thickness may affect kernel integrity; the pericarp must be broken or torn before a kernel can break into two or more pieces. Pericarp permeability may also be a factor in drying rate (Purdy and Crane, 1967).

Test weight history is related to need for hardness of endosperm. Back when 90% of Corn Belt corn was fed to livestock on the farm where it was produced, test weight was of no consequence -- unless it was too high causing flinty kernels to pass undigested through livestock. Low test weight became a problem with field shelling, grain driers, and cash-grain farming in the 1960's. As long as corn was harvested on the ear and the grain dried slowly in a crib, test weights were almost always above grade standards. But, case-hardened and puffed kernels from high temperature drying made heavier test weight an imperative characteristic for successful corn breeders. During the 1960's one company spent six years' breeding effort at four research stations to adjust to this need for higher test weight. About half a million test weight determinations were taken as an additional characteristic for selection. Today, test weight is taken on most corn research test plots.

Genotypic variability

Nearly all corn grown for commercial production in the United States is single cross corn. Single cross hybrids are produced by crossing two homozygous (true breeding) inbreds, so single cross plants are quite uniform. The kernels on the ears of single cross plants are one generation advanced, and consequently segregate for traits where the parent inbreds differed. Also, pollen grains blowing into the field from other corn hybrids have an immediate effect (xenia) on the kernels they fertilize. Dent corn classes specify that yellow corn can contain no more than 5% white kernels and white corn can contain no more than 2% yellow. Popcorn or sweet corn kernels in dent corn are defined as foreign material. Flint corn must be 95% or more Flint. Waxy corn must be 98% or more waxy.

Genetic versus environment

The environment greatly influences the quality of the grain. As mentioned earlier, fall seasons with much rainfall can increase ear rotting. The need for fast drying in the field has caused selection of hybrids with less husk cover. These same hybrids may lack ear protection when exposed to heavy rainfalls. The best hybrid for fast drying in a normal fall may be the worst hybrid for ear rot in a high-rainfall fall. Early frosts may cause premature death that reduces kernel size and test weight. In general, dry seasons favor insects because insect parasites are inhibited by lack of moisture. Insects reduce grain quality by increasing broken kernels, foreign material, and kernel rots. Drought stressed corn that is left in the field to dry in humid falls (most corn dries in the field in the southeast U.S.) is more likely to become contaminated with aflatoxin.

Genetic versus management

Protein content can be increased with nitrogen fertilizer. If the base yield is 75 to 100 bushels per acre with 8.5% protein, and the final yield with extra nitrogen is 100 to 125 bushels, the first 100 pounds of N will probably raise the protein about 1 percent. The next 100 pounds of N will raise the protein another 0.5 percent (Aldrich and Leng, 1966). Higher protein contents have been found in corn grain after drought conditions because a fixed nitrogen amount is distributed through a smaller crop (Genter, et al., 1948). This is because most N accumulation precedes endosperm filling. Only one fourth of the protein in the kernel is in the endosperm. The endosperm increases in size with higher yields and is mostly starch--86% starch and 9% protein (Watson, 1977). Thus, at high yield levels or at low nitrogen fertilization levels a negative association occurs between yield and percent protein.

Plant density can affect quality when enough stress occurs to cause misshapen ears that may dry slowly or have more small kernels. Grain texture may also be affected by stress. Late planting dates reduce quality by causing flowering during hot weather and by causing an immature crop at harvest with effects similar to early frost.

Early harvesting dates with grain moistures above 25% increases kernel breakage compared to lower harvest moistures (Peplinski, et al., 1975). Minimum field losses due to broken stalks or dropped ears occur at about 26% grain moisture (Aldrich and Leng, 1966).

Drying method is a big factor in corn quality. As long as corn was harvested on the ear and dried slowly in the crib, test weight and broken kernels were no problem. Field shelling (combining) has changed all that. In the northern and central Corn Belt, harvest at high moisture followed by rapid drying at high temperatures can cause puffing and case-hardening that reduces test weight and increases brittleness. In the southern Corn Belt, ear quality can deteriorate in the field during humid fall conditions.

Ear corn storage has given way to shelled corn storage. It is rare now to see corn cribs or for boys to have corn cob fights. About the only source of corn cobs is seed corn plants. As mentioned before, these changes in harvest methods have greatly affected corn breeders' selection traits. Stored corn typically has problems with molds and insects that interact with moisture content and temperature of the corn. Breeders are not usually held accountable for problems that develop in stored corn.

Institutional influences on selection

Corn breeding at the federal, state, and private level greatly increased subsequent to the double-cross-corn formula of hybrid production that made hybrids practical in spite of the weak inbreds and with cultural practices of the period (Jones, 1922). Frederick Richey was put in charge of corn investigations for the U.S.D.A. in 1922; he expanded and organized the federal and state work. In 1955 Henry A. Wallace estimated the Federal Government spent $300,000 ($80,000 for basic research), State Experiment Stations less than $150,000, and private companies more than $2,000,000 annually on corn breeding and yield testing (Wallace, 1955). Comparable estimates for 1987 are Federal Government (USDA) $4,000,000, State Experiment Stations (CSRS)

$8,000,000, and private companies more than $70,000,000. For comparison, the 1987 budget contained (USDA-ARS) $35,000,000 and State Experiment Stations (CSRS) $46,000,000 for projects related to biotechnology (Bentley, 1987).

Federal and state policies and regulations affect corn breeding. Inbreds are valuable resources in the seed corn business. Until about 1960, most state experiment stations had delayed-release programs for new inbreds that served to maintain state crop improvement programs by favoring companies that sold state-certified hybrids. Delayed release policies plus the Federal Seed Act of 1939 (USDA, 1975), which prohibits selling the same pedigree under different names, effectively excluded new public inbreds from private label seed companies.

At the beginning of hybrid corn, many small seed corn companies were enticed into the business by promises of new inbreds from the State Experiment Stations. Inbred lines from public agencies became the parental lines for station hybrids and became the parental lines for development of new inbreds. By the late 1950's, larger seed corn companies had extensive research programs to develop inbreds and public breeders started doing more basic research at the expense of inbred development. Dr. Merle Jenkins showed that from 1946-55 a total of 156 public lines were released. An American Seed Trade Association survey of the same period showed 52 hybrid corn companies in 12 states were using these lines as one or more parents in producing about one fourth of the hybrid seed used annually (Johnson, 1957). In Iowa in 1940, about 500 individual companies produced and sold hybrid seed with only about 100 companies still in operation in 1957 (Johnson, 1957).

Dr. George Sprague talked on basic research in the federal and state corn improvement programs in 1959 and presented the following conclusions: publicly supported corn research was more basic than it had been ten years earlier, the breeders involved felt that even more time should go to basic research; local pressure would continue to affect amount of effort on basic research, and public efforts would contribute to the hybrid corn industry through basic research as importantly in the future as they had with applied research in the past (Sprague, 1959).

Regional cooperative testing programs of federal and state breeders along with extensive testing programs of large seed companies have identified widely-adapted materials. Increased emphasis on results from many locations probably results in better grain quality because more hazards are encountered before release. Both farmers and seed companies benefit from superior, widely-adapted popular hybrids.

Differentiation of public and private breeders

Private breeders must produce marketable products. Time pressure usually causes more emphasis on short range efforts in commercial programs. Public breeders by definition are funded by tax dollars, funds from commodity groups, etc., which gives them more freedom to engage in a wider range of breeding interests. Private and public breeders do not compete for the same funds. Perhaps the public breeder can attempt higher risk research or work on projects for smaller markets than the private breeder. The number of farmers in the U.S. has decreased from some 70 million during the Civil War to four or five million today. This decrease in farmers has reduced agricultural representation in both federal and state legislatures, thus the erosion in public funding for corn breeding will continue, in spite of the obvious past and present successes. In contrast, public funding for biotechnology will continue to increase.

Breeding for specific markets

The white corn market is less than 1% of annual U.S. corn production. Most white corn is used for certain food products. Some funding of white corn breeding is done by Quaker Oats Company to public breeders; private companies do some white corn breeding.

The waxy and high amylose corn markets are less than 1% of annual U.S. corn production. These endosperm mutants are grown under contract for wet millers because purity requirements are high (98%), because a premium price is paid, and because neither mutant competes with dent corns for yield and other agronomic traits. Starch of waxy corn is 100% amylopectin, which is a highly branched molecule. Starch of high amylose corn has 50-70% straight molecules. Dent corn usually has about 27% amylose and 73% amylopectin starches. Breeding for starch type is done by public breeders and by a few small private companies.

The high lysine corn market is less than 1% of annual U.S. corn production. High lysine corn requires less protein supplement in a balanced diet for animals with simple stomachs (swine and humans). Commercial high lysine corn hybrids have been available but were generally lower yielding and slower drying than dent corn counterparts. Very little breeding work on high lysine corn is presently being done in the U.S..

Dry millers process about 1.5% of the annual U.S. corn production. Primary products from dry milling are corn grits, corn meals, and corn flours used for by-products animal feed, brewing, breakfast cereals, fermentation for pharmaceuticals, baking mixes, gypsum board, foundry binders, and snack foods (Alexander, 1987). Corn grit yield from dry milling depends on the hardness (lack of soft starch) of the milled corn. Therefore, breeding effort for kernel integrity, better test weight, etc. that makes better corn for export will also help dry millers.

Wet millers process about 10% of the annual U.S. corn production. Wet milling involves a carefully controlled water soak to soften the kernels before milling. Milled corn is separated and processed to produce sweeteners as the largest volume product followed by corn-gluten feed and meal-starch products, corn oil, and ethanol. Normal dent corn is the predominant type used by wet millers. About 1.5% of wet-milled corn is waxy and 0.2% is high amylose (May, 1987). Waxy and high amylose corns are kept separate from dent corn in the wet milling process. Again, breeding effort for kernel integrity for export markets will also help wet millers because broken kernels are screened out for livestock feed prior to wet milling.

Number of hybrids and inbreds

Based on a 1981 survey, 454 commercial hybrids were offered for sale, 212 pre-commercial hybrids were in final testing stages, and 7,400 experimental hybrids were in advanced trials and 61,000 hybrids in preliminary trials; about 2,800 proven inbreds were on hand and 23,000 inbreds were in preliminary tests (Duvick, 1981).

Procedure for release

New inbreds and hybrids are tested in many areas as quickly as possible so that limits of adaptation are identified. Product advancement schemes insure both that hybrids are tested widely and that seed supplies are increased sufficiently for the next level of testing that leads to release. Over a five or six year period testing sites increase from three or four to 30 or 40 geographical locations per year. The last stage is usually strip testing by farmers to compare the new hybrid with available hybrids on the market under farmer conditions. A new commercial hybrid has usually survived more than 200 tests during the four or five year period before it is offered for sale.

Tests conducted, new tests needed

The most important traits measured in yield tests include yield, grain moisture at harvest, percent stalk broken, percent root lodged, and percent dropped ears. Additional traits commonly taken include seedling vigor, percent early stand, flowering date, plant height, ear height, percent barren plants, stay-green, percent final stand, test weight, and relative maturity. Only test weight relates to kernel hardness or kernel integrity and test weight is not always taken in the early stages of testing where larger differences occur. New tests might include breakage tests (Stein or Wisconsin) where kernels are impacted against a hard surface, sieving tests to separate cracked kernels, or staining tests (Paris green) to show surface cracks in kernels.

Patenting and licensing effect

The U.S. Congress enacted the Plant Variety Protection Act in 1970. PVP was designed to be an incentive for private industry to develop true breeding crops such as small grains and soybeans, but PVP has also been used to protect corn inbred lines. Congress passed amendments to PVP in 1980 to expand protection. Also in 1980, the U.S. Supreme Court ruled that a patent could not be denied for a new invention simply because the subject matter was living. Since that time the trend has been to increase PVP and utility patent claims to protect corn inbreds and hybrids.

Plant variety protection and utility patents provide for protection of ownership of corn germplasm. Protection is desirable as an incentive to development—research is expensive. Ownership of corn germplasm is an active area of interest.

Adequacy of germplasm base

Most of the U.S. Corn Belt germplasm used today involves only two races, southern dents and northern flints, but more than 100 fairly distinct races of corn exist. From this standpoint the available germplasm base is more than adequate. Probably as much genetic variability exists among kinds of corns as among kinds of dogs for adaptation, for size, and for purpose. It is likely that any and all traits that are needed to improve corn quality already exist. The problem is to identify exactly what is needed so that seedlots in germplasm banks can be efficiently screened for the necessaray traits. Certainly a large range of test weight, kernel texture (ratio of hard to soft starch), and kernel size, is presently available among materials actively being used by U.S. corn breeders. The hope that an existing unidentified trait for kernel integrity can be found depends on an accurate test to identify it.

Present breeding technology

Present corn breeding technology has worked well (Figure 1). U.S. average yields are increasing almost two bushels per acre per year largely due to the highly competitive seed corn industry striving to provide hybrids that give the highest net profit to the farmer. Presently, corn breeders emphasize high yields, easy harvest, and fast drydown with modern cultural practices. History shows that breeders' priorities change as needed to develop successful products in response to changing markets and to agricultural practices. The present system relegates grain quality to fourth rank or lower. Making grain quality or any other desired trait more profitable to the farmer will stimulate more breeding effort for that trait with the present system. The first logical step is to provide a market for and pay for grade No. 1 corn. Paying the farmer for higher quality will immediately increase corn quality in marketing channels; further, it will immediately stimulate corn-quality breeding effort.

Future breeding technology

Future corn breeding technology will include more of the present methods plus more biotechnology. Net profit for the farmer is paramount. Successful breeders are fitting these newer technologies into present methods. Transformation of plants with genes from other species and with engineered genes may provide the needed trait with less effort and less extra baggage than screening various germplasm storage banks. Regeneration of tissue from elite lines may provide the needed mutant trait in a desired background that currently satisfies farmers' needs. Ultimately, it may be possible to build a needed DNA sequence and position it into elite lines.

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Table 1. Grades and grade requirments for corn.

Grade	Minimum Test weight per bushel	Maximum limits of--		
		Broken Corn and foreign material	Damaged Kernels	
			Heat damaged kernels	Total
	--------------------%--------------------			
U.S. No. 1	56.0	2.0	0.1	3.0
U.S. No. 2	54.0	3.0	0.2	5.0
U.S. No. 3	52.0	4.0	0.5	7.0
U.S. No. 4	49.0	5.0	1.0	10.0
U.S. No. 5	46.0	7.0	3.0	15.0
U.S. Sample Grade	----	---	----	---

Table 2. Summary of studies on breeding gain in corn.

Study	Hybrids	Period	Gain
	No.	Yrs.	%
Duvick, 1977	19	32	57
Duvick, 1977	50	40	60
Russell, 1974	25	48	63
Castleberry, et al., 1984	27	60	75
Average	30	45	64

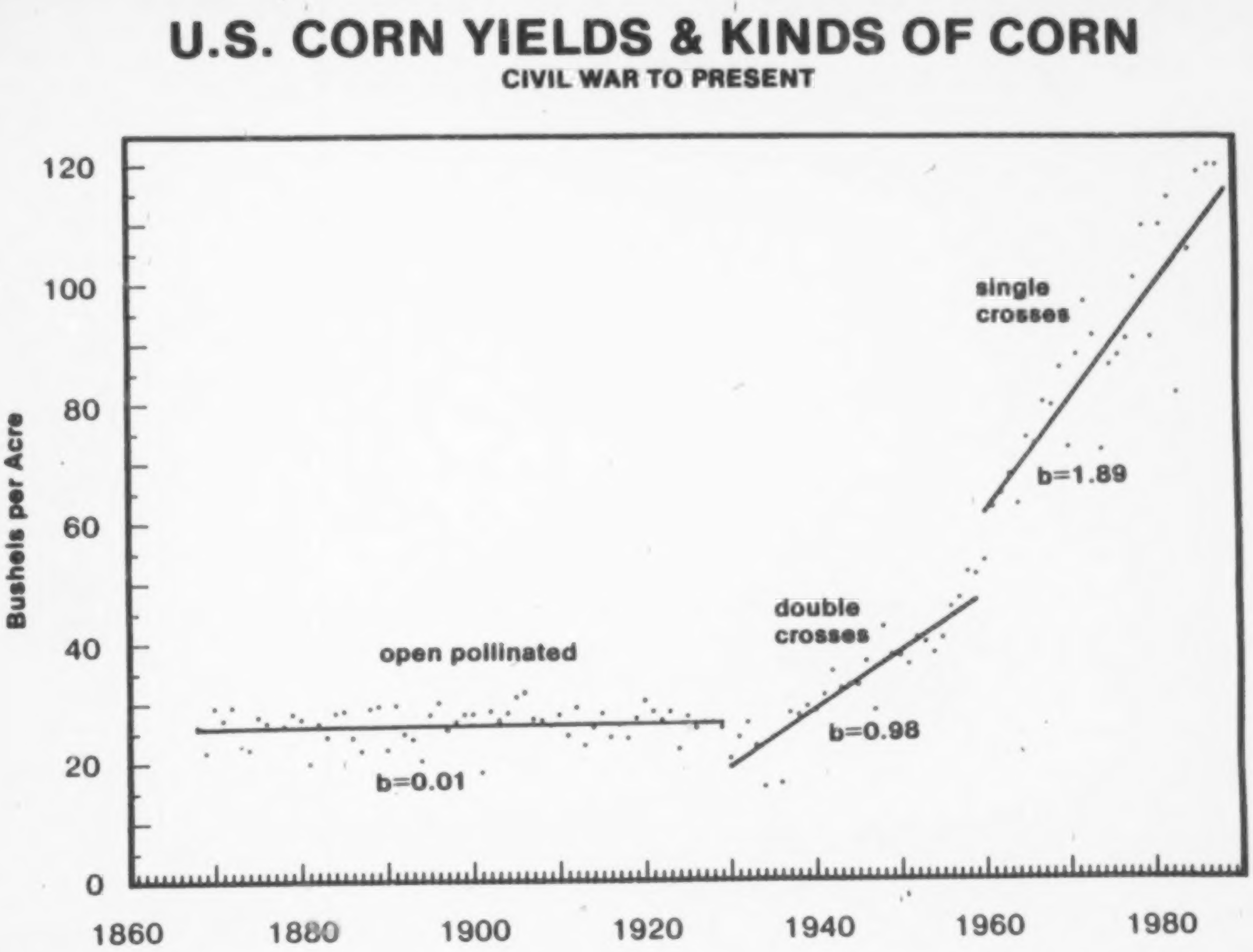

FIGURE 1. U.S. corn yields and kinds of corn over years; b values show average yield increase per year for kinds of corn.